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FIRST ANNUAL

ACADEMIC APPAREL RESEARCH CONFERENCE

ON

ADVANCED APPAREL MANUFACTURING TECHNOLOGY DEMONSTRATION

FEBRUARY 14-16, 1990

PHILADELPHIA, PA

PROCEEDINGS

VOLUME 1

REPORT DOCUMENTATION PAGE

16 Feb 90

FINAL 14-16 Feb 90

FIRST ANNUAL ACADEMIC APPAREL RESEARCH CONFERENCE ON ADVANCED APPAREL MANUFACTURING TECHNOLOGY DEMONSTRATION

N/A

PHILADELPHIA COLLEGE OF TEXTILES & SCIENCE
PHILADELPHIA, PA

N/A

DEFENSE LOGISTICS AGENCY
CAMERON STATION
ATTN: DLA-PRM
ALEXANDRIA, VA 22304-6100

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INCLUDES AGENDA, OVERVIEW, AND PRESENTATION MATERIAL ON ADVANCED APPAREL MANUFACTURING TECHNOLOGY DEMONSTRATION CONFERENCE.

800

AAMTD, MANTECH, APPAREL

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ACADEMIC APPAREL RESEARCH CONFERENCE

on

ADVANCED APPAREL MANUFACTURING TECHNOLOGY DEMONSTRATION

FEBRUARY 14, 1990

12:00 - 01:00	REGISTRATION & BOX LUNCH INTRODUCTIONS	
01:00 - 01:45	TEXTILE/CLOTHING TECHNOLOGY CORPORATION	J. OFF
01:45 - 02:30	FASHION INSTITUTE OF TECHNOLOGY	H. SEESSELBERG
02:30 - 03:15	CLEMSON UNIVERSITY	C. JARVIS
03:15 - 03:30	BREAK	
03:30 - 04:15	GEORGIA TECH/SOUTHERN TECH	J. ADAMS/ HADDOCK
04:15 - 05:00	NORTH CAROLINA STATE UNIVERSITY	T. LITTLE
05:00 - 05:45	UNIVERSITY OF SOUTHEASTERN LOUISIANA	A. STEWARD
05:45 - 06:15	PCT&S: MECHANICAL PROPERTIES OF FABRICS	H. BARNDT
06:15 - 06:30	IMPLICATIONS FOR GOVERNMENT AND INDUSTRY	D. O'BRIEN
06:30 - 07:30	RECEPTION	

ACADEMIC APPAREL RESEARCH CONFERENCE

on

ADVANCED APPAREL MANUFACTURING TECHNOLOGY DEMONSTRATION

February 15, 1990

07:30 - 08:30	Registration & Continental Breakfast		
08:30 - 10:30	SIMULATION		
	A LOOK AHEAD	USL	DELCAMBRE
	SIMULATION	TC2	OFF
	DISCRETE EVENT/TROUSERS	GT	SOMMERFIELD/ TINCHER
	LOOK AHEAD SHOP FLOOR	CU	PECK/PARGUS
	OPERATIONS A		
	SUPERVISORY TRAINING	FIT	WALFISH
	COURSE:SUPERVISOR/ ERGONOMICS	GT	ORITZ/KELLY
	PROB. SOLV: PIECE GOODS	CU	CHRISMAN
	ANALYSIS/IMPROVE APPAREL MACHINES	FIT	SCHORR
	MECHANICAL ENGINEERING: A		
	PROB. SOLV: SEW LABELS	CU	ASPLAND
	ATTACHMENTS	TC2	HUGHES
	FLEXIBLE MODULES	NCSU	McPHERSON
10:30 - 10:45	BREAK		
10:45 - 12:45	APPAREL		
	APPAREL MFG DATA BASE	NCSU	CARRERE
	KNOW. BASED FRAMEWORK: TROUSER PROCUREMENT	GT	JAYARAMAN
	KNOW. BASED FRAMEWORK: TROUSER DEFECTS	GT	JAYARAMAN
	ECONOMICS		
	MARKET SURVEY	NCSU	BERKSTRESSER
	INTEGRATED COST MEASUREMENT SYSTEM	CU	McKNEW/ PRATER

10:45 - 12:45	MATH MODELING		
	DEFINITION: FLEXIBILITY	NCSU	HODGE/CANADA
	PROB. SOLV: HIERARCHAL PROD. PLAN	CU	JARVIS
	CUT ORDER PLAN: TROUSER MFG.	GT	JACOBS/ AMMONS
	PROD. PLAN. FOR QR	CU	KANET/DAVIS
	AUTO. MARKER MAKING	GT	JACOBS
12:45 - 01:45	LUNCH		
01:45 - 03:45	COMPUTER INTEGRATED MANUFACTURING		
	OPERATING SYSTEM FOR DISTRIBUTED MFG.	CU	PECK/ MADISON
	INTERFACE STANDARDS	USL	DELCAMBRE
	ARCH. FOR MFG. UTILITY TROUSERS	GT	JAYARAMAN
	OPERATIONS B		
	COST & PROD. DATA BUNDLE vs UPS	FIT	KORNGRUEN
	COST & PROD. DATA BUNDLE vs UPS	CU	HILL
	FLEXIBLE WORK GROUPS	GT	JACOBS
	FLEXIBLE WORK GROUPS	CU	HILL
	MECHANICAL ENGINEERING: B		
	PLY SEPARATION	NCSU	CLAPP
	PROB. SOLV: AIR FLOTATION	CU	ASPLAND
	ROBOTIC ASSIST: SHIRT COLLARS	CU	PAUL
03:45 - 04:30	FACILITIES TOUR		
05:00 - 07:30	RECEPTION & DINNER		

FEBRUARY 16, 1990

07:30 - 08:30	CONTINENTAL BREAKFAST		
08:30 - 10:30	APPAREL		
	DEV. PATTERNS & PROTOS: NAVY, WOMENS	FIT	JAFFEE
	STITCHLESS TECHNOLOGY	CU	JARVIS
	IMPROVED MFG. METHODS: PEA COATS	FIT	BRENNER
	MECHANICAL ENGINEERING: B		
	ROBOTICS FOR PRESSING	RPI	HANNIFIN
	DRAPER LABS.	TC2	BERNARDIN
	PROGRAMMABLE SEWING M/CS	FIT	SEESSELBERG
	OPERATIONS B		
	PROB. SOLV: CARPEL TUNNEL	CU	HILL
	MAINTAIN WIP (SOFTWARE SURVEY)	FIT	KAHN
	VIDEO DISC	TC2	HUGHES
10:30 - 10:45	BREAK		
10:45 - 12:45	ECONOMICS		
	NON TRADITIONAL ECO. ANALYSIS	CU	KANET
	NON TRADITIONAL ECO. ANALYSIS	GT	RIALL
	NON TRADITIONAL ECO. ANALYSIS	FIT	SEESSELBERG
	COMPUTER INTERGRATED MANUFACTURING		
	PROB. SOLV: AGV	CU	PECK
	APDES	NIST	HOPP
	ELECTRONIC BULLETIN BOARD	CU	MADISON
	MECHANICAL ENGINEERING: A		
	AUTO FABRIC INSPECTION	CU	JARVIS
	IN-PROCESS QC: FABRIC DEFECTS	GT	TINCHER/ DALEY
	IN-PROCESS QC: SEWING DEFECTS	GT	OLSON/ SIKORSKI

12:45 -- 02:15	LUNCH & CONCLUDING REMARKS
02:15 - 04:15	PLANT TOUR: OPTIONAL DEFENSE PERSONNEL SUPPORT (On the way to the airport)

FEBRUARY 14, 1990

TEXTILE/CLOTHING TECHNOLOGY CORPORATION

OVERVIEW

$(TC)^2$

TEXTILE/CLOTHING TECHNOLOGY CORPORATION

APPAREL TECHNOLOGY CENTER

Prepared by Frank H. Hughes
Presented by Joseph W.A. Off (April 22, 1988)

Since its inception in 1980, $(TC)^2$ has pioneered leading-edge technology developments for the apparel industry.

The vision-guided robotic sewing systems developed by Draper Labs in Cambridge, MA, have paved the way for many automatic sewing applications such as the ones that are being commercialized by Singer today.

The funding of this effort at Draper and other development activities is supported by the more than 50-member coalition of fiber producers, textile and apparel manufacturers, unions and the U.S. government.

This on-going high-tech thrust to strengthen the competitive position of the U.S. apparel industry will now be further enhanced by the services of $(TC)^2$'s new apparel technology center in Raleigh, NC.

The initial mission of this tech center is directed at addressing the fact that the majority of U.S. apparel manufacturers do not fully utilize commercially available state-of-the-art machinery and systems.

With this premise in mind, the center has set forth these main objectives:

1. to DEMONSTRATE in a credible manner the latest state-of-the-art machinery, computer systems and methodology for apparel manufacturing.

2. To foster the utilization of these systems by EDUCATING apparel manufacturing management, engineers and technicians in the benefits, capabilities, operation and financial ramifications of these systems.

3. To carry out SHORT-TERM DEVELOPMENT activities that would enhance the performance and product quality of existing production equipment.

In general, these objectives will be accomplished by:

1. Operating a complete <u>APPAREL PRODUCTION LINE</u> using state-of-the-art technology.

2. The evaluation and application of <u>COMPUTER SIMULATION MODELING</u> systems for design and manufacturing modification analysis.

3. The <u>BETA TESTING</u> of $(TC)^2$ and other development systems in a controlled production environment.

4. Sponsoring RESEARCH PROJECTS with N.C. State University and other academic institutions.

5. Performing in-house SHORT-TERM DEVELOPMENT activities.

6. Conducting SEMINARS AND SHORT COURSES along with comprehensive long-term hands-on MANAGEMENT DEVELOPMENT PROGRAMS for managers, engineers, technicians and students.

PRODUCTION LINE

The manufacturing line will:

1. Initially produce high-quality men's dress slacks.

2. Operate on a full production basis three (3) days/week.

3. Function from pattern design, markermaking, cutting and stitching through final pressing and packaging.

4. Be operated by 12-16 operators cross-trained to perform 3 to 4 operations each.

5. Apply and compare various manufacturing methodologies such as:

   - progressive bundling system
   - unit production system
   - modular manufacturing

6. Utilize the latest computer systems for:

   - Management Control
   - Product Design
   - Planning
   - Production Control
   - Engineering
   - Data collection --- just to mention a few.

All of which is directed at achieving a fully integrated and paperless manufacturing system. This pant line started training in February 1988 and is progressing well.

The acquisition of the equipment and computer systems required to operate this production line, along with that of the entire facility, has been a most rewarding experience. We have the commitment for and are currently receiving over 60 machines and 34 software systems from 48 suppliers.

The $(TC)^2$ membership, Executive Board and Board of Directors are most appreciative of [illegible] standing support, and we assure all those that have provide [illegible] at they will be operated in a very professional and

efficient manner for the benefit of the entire industry.

BETA TESTING

The Beta testing function will provide an opportunity for $(TC)^2$ and other industry suppliers to test their systems in a production environment. This will provide $(TC)^2$ development contractors and machine suppliers with advantages such as:

- A broad input of product requirements
- Production experience with strong technical feedback
- Recommendations and assistance from $(TC)^2$'s in-house technical and management staff on changes and improvements.

$(TC)^2$ members can view, collect data and analyze these systems without disrupting their own production facilities.

We currently have five (5) systems scheduled for Beta testing which will begin on our February 1988 start-up.

$(TC)^2$ FUNDED ACADEMIC RESEARCH

The need for academic research to supplement commercial technology development is a vital key to the long-term success of our efforts and that of the entire industry. We have initiated our first academic research project with N.C. State University's College of Textiles and Industrial Engineering.

Phase I of this project is directed at another industry buzzword, namely **Computer Simulation and Modeling**. As is the case with other new industry buzzwords -- there is a great deal of talk -- limited action -- and in many cases, a total lack of understanding about the subject.

Computer Simulation and Modeling is not a new technology. It's simply not utilized by our industry. Simulation and Modeling has primarily been used to analyze manufacturing systems. It has also been applied to such activities as patient analysis and management in hospitals and the evaluation of paperwork flow in administrative functions.

Simulation systems provide you with the opportunity to build a computer model of any function from a single machine to a complete manufacturing facility.

They allow you to construct models, for example:

1. To compare equipment or systems
2. To reduce new system evaluation risk factors
3. To evaluate product or equipment changes

4. To evaluate: scheduling
5. manufacturing costs
6. manpower requirements
7. thru-put time
8. in-process inventory

and, in general

9. Play the "What If" game

The advancements in these systems have lead to methods for easier model building techniques and very effective animation graphics. In other words, they do not require a compute modeling expert to design the model and run the simulation. They are currently configured for the end user -- whether he be:

- an engineer evaluating a design
- a manufacturing manager evaluating a new production line, or
- an industrial engineer evaluating a new method or product change.

The point is that they are designed for the person who primarily understands the process to be modeled -- not the modeling process.

Although the end result of a simulation model is going to be data illustrating the results of the model, the actual building of the model and the operation analysis is further enhanced by 3D graphic displays of the actual model n animated form.

We have chosen a system of Simulation and Modeling for immediate use at our center. We will initially apply it to verify our production configuration and to evaluate Beta systems and proposed development projects. It will also be offered as a service to member companies for their modeling requirements.

On the long-term basis, other systems may be ultimately more advantageous for industry-wide use.

Therefore, our research project is directed at comparing three (3) of the most advanced systems for adaptability to the broad range of apparel industry requirements. In addition, this research project will concentrate on the front end or user input side to even further simplify the model building and operation of the system.

This project is scheduled for completion by August 1988.

SHORT-TERM (in-house) DEVELOPMENT ACTIVITIES

The Apparel Technology Center is prepared to make an accelerated effort in the area of short-term (3 to 6 months) development projects. We currently

have the capability to design, fabricate, assemble and production test:

1. Improvements to existing machines
2. Automatic feeding and take-away units for performance enhancement
3. Integrated or married systems
4. Total systems

Several operations have been identified for improvement during our pant-line configuration studies. The related machinery development projects for these operations will begin in June of this year.

The projects will be completed on an independent basis and in cooperation with machine suppliers and outside development sources.

In addition, we will maintain a knowledge base of development activities so as to co_n the old phrase -- "not reinvent the wheel." This will help control our development efforts and will be available to assist other development organizations as well.

MANAGEMENT DEVELOPMENT AND EDUCATIONAL PROGRAMS

Seminars and Short Courses:

A broad range of seminars and short training programs will be offered to:

- Top Management
- Middle Management and Engineers
- Fast Trackers and Aggressive Management Trainees
- Academia
- Students

The subject matter of these programs will be very specific and attendees will take an active hands-on role in the sessions. They will not only learn about the machines, computer systems and methods, but they will also come away from the sessions with a very practical understanding of the system through their actual use and operation during the training sessions.

Management Development Programs:

A number of longer term (3 to 9 month) programs are in the formulation phase for industry and academia.

1. Management development programs for Fast Trackers and trainees will include all aspects of the production process, machines, and systems. (These attendees would be assigned to the center for the duration of the program.)

2. Students under part-time employment and co-op programs would have an opportunity to obtain practical experience in their chosen field as it relates to apparel manufacturing.

The objectives -- along with the continued long-term technology development program -- represent $(TC)^2$'s "Meet the Challenge" response to the ever-increasing tide of textile and apparel imports.

We are confident that the apparel technology center will represent an important contribution to the long-term success of our industry.

We invite you to visit our center, take advantage of our services and become an active member of $(TC)^2$'s team where you will help shape the future of our industry.

FEBRUARY 14, 1990

FASHION INSTITUTE OF TECHNOLOGY

OVERVIEW

(PAPER NOT AVAILABLE)

FEBRUARY 14, 1990

CLEMSON UNIVERSITY

OVERVIEW

CLEMSON APPAREL RESEARCH

STRIVING TO REVITALIZE THE DOMESTIC APPAREL INDUSTRY THROUGH THE PROPER APPLICATION OF ADVANCED TECHNOLOGY AND BETTER MANAGEMENT TECHNIQUES.

Clemson Apparel Research (CAR) was funded in August, 1987 as a contract with the US Defense Logistics Agency. Additional funding is provided by Clemson University and the State of South Carolina. CAR is part of Clemson University and is a major research effort in the School of Textiles. The major objectives of CAR are:

- Operation of a model apparel plant demonstrating state-of-the-art manufacturing technology and innovative management techniques

- Assisting apparel manufacturers on the use of non-traditional capital investment criteria in the purchase justification of advanced manufacturing technology: Apparel Manufacturing Capital Investment Advisory (AMCIA)

- Provide an on-line computer bulletin board service announcing important apparel industry events and new products: Apparel Management Information Service (AMIS)

- Conduct research projects which serve to improve apparel manufacturing by the creation of new technologies and management systems.

The most visible portion of CAR is the model apparel plant which is located in Pendleton, SC approximately eight miles from the main University campus. The plant consists of 6,000 sq ft of office space, a 6,000 sq ft demonstration area, a 12,000 sq ft warehouse, and a 1100 sq ft classroom. On an average month, 200 people visit CAR. Approximately half of these people are associated with the apparel industry. The remainder range from civic groups to classes at Clemson. The latter visitors are also important because they help to improve the image of the apparel manufacturing industry.

CAR conducts a number of research and service projects for the apparel and textile industries ranging from small projects to larger studies. During recent months CAR personnel have become more involved with projects for the Department of Defense such as looking at garment redesign for improved wearer satisfaction and enhanced manufacturability. In the future CAR expects to work more closely with apparel defense contractors in modernizing their manufacturing capabilities.

Among the research projects currently underway at CAR:

"Development of an Integrated Shop Floor Production Cost Measurement System for an Automated Apparel Manufacturing Facility" Principal Investigator: Mrs. Mary Ann Prater
The objective of this project is to develop an integrated product costing system (IPCS) that uses data generated directly from factory operations. Once the costing system is developed, it will be implemented at the Clemson Apparel Research facility, and compared to other cost systems currently in use in apparel

manufacturing. The information will provide company management with improved cost and decision making information by measuring operational performance and efficiency.

"Develop a Computer Operating System for Distributed Manufacturing"
Principal Investigator(s): Drs. J. Peck and W. Madison
The purpose of this project is to design and develop a set of generalized software, called the Distributed Operating System (DIOS), which would allow the operational characteristics of the apparel workstations to be dynamically changed as the needs of the workstation change. This will be accomplished through coordination and integration with related AAMTD projects, and the development of a multiprogramming computer operating system to run within a local area network.

"Look Ahead Simulation of Shop Floor Operations"
Principal Investigators: Drs. R. Pargas and J. Peck
The current state of apparel manufacturing software provides an accurate, real-time assessment of the shop floor operation at any given time. What is not available, however, is a precision tool that provides the manager with timely information and fine-tuned control over daily operations. This research effort hopes to provide this tool to the manager. The objectives of this research are: (1) to accurately model the manufacturing process, (2) to implement the model first on a single-processor computer, then on a multiple-processor system, and (3) to evaluate the performance associated with each of the implementations.

"Robot Assisted Material Handling for Shirt Collar Manufacturing"
Principal Investigator: Dr. Frank Paul
This research addresses the design and development of a robotic fabric handling system (RFHS), which can interface with an apparel assembly task to create an apparel assembly workstation (AAW). A general purpose industrial robot, sensored end-effector, and high speed data vision system for controlling robot motion compose the RFHS. The objective of this research is to demonstrate the feasibility of applying flexible automation in the form of robotics and workstation concepts to apparel manufacturing. Experimental evaluation of the RFHS is being conducted at the Clemson Apparel Research facility.

"Production Planning for Quick Response in the Apparel Industry"
Principal Investigators: Drs. J. Kanet and S. Davis
The objective of this research is to develop and evaluate several competing approaches to production planning which, in contrast to MRP-based approaches, simultaneously determine both a production schedule and material plan. The study is being conducted by developing a prototype computer system, performing controlled experiments on the system, and observing its performance under a variety of operating conditions. An important aspect of the work is the transfer of the knowledge gained so that others may build on it; therefore, results will be publicized through research and apparel trade conferences, and the algorithm will be demonstrated at the Clemson Apparel Research facility.

"Comparison of Cost and Production Data Between a Traditional Bundle System and a UPS Installation"
Principal Investigator: Mr. J. Edward Hill

This project will compare the costs of manufacturing the Army 415 short-sleeved green shirt on the bundle system and a Unit Production System (UPS). UPS costs will be derived from actual production costs incurred at the Clemson Apparel Research facility, while bundle costs will be actual production data obtained from at least two current military shirt manufacturers. The statistical data and conclusions will be made public.

"Flexible Work Groups" Principal Investigator: Mr. J. Edward Hill
The purpose of this research is to assemble information from U. S. and Japanese Companies currently using Flexible Manufacturing Units, establish a Flexible Manufacturing Unit at the Clemson Apparel Research facility, and conduct public demonstrations relating the knowledge gained through this effort. The objective of the project is to investigate the applicability of flexible work groups to military apparel manufacturing.

"Development of a Guiding System for Air-Floatation Spreading"
Principal Investigator: Mr. Antony J. Aspland
The objective of this project is to design, test, demonstrate, and distribute plans for a spread guiding system which can be retrofitted to any air-floatation spreading table.

"Production Process Improvement for Sewing Strip Labels to Collar-Bands"
Principal Investigator: Mr. Antony J. Aspland
The need to solve the manufacturing problems of sewing strip labels to collar-bands, while maximizing positive consumer impressions, is basic necessity of the apparel industry. The objective of this research is to solve the current apparel production problems associated with the labeling of garment collar-bands.

"Hierarchical Production Planning and Scheduling in the Apparel Industry"
Principal Investigator: Dr. James Jarvis
Hierarchical production planning and scheduling has been shown to be effective in a continuous-process environment characterized by both seasonal and make-to-order demand. This approach embodies mathematical and computing techniques not widely accessible in the apparel industry. The objective of this project is to ascertain the applicability of these methods in apparel manufacturing.

"Measuring the Effectiveness of AAMTD" Principal Investigator: Mrs. Patricia P. Watkins
The objective of this research is to produce a quantitative assessment of the effectiveness of the apparel demonstration project at Clemson University (Clemson Apparel Research), including an assessment of the impact of the demonstration project on both the U. S. apparel manufacturing industry, and the clothing procurement by the military.

"Develop a Business Plan"
Principal Investigator: Dr. Christine W. Jarvis
The purpose of this research is to develop a strategy for ensuring the continuation of the Clemson Apparel Research facility after the conclusion of five years of government funding.

"Develop Machinery to Assemble Shirt Collar Bands to Collars"

Principal Investigator: Dr. Marvin Dixon
This research proposes to demonstrate the feasibility that an advanced collar banding prototype workstation can effectively be applied to apparel manufacturing in the context of apparel assembly workstations (AAW's) and apparel assembly cell (AAC).

"Minimization of Carpal Tunnel Syndrome" Principal Investigator: Mr. J. Edward Hill
The purpose of this research is to develop an attachment and a method that will greatly reduce the risk of carpal tunnel syndrome from a side seam operation called French Felling II.

"Problem Solving for Apparel Manufacturers - Automated Guided Vehicles""
Principal Investigator: Dr. Jack Peck
This contract is awarded to develop a user friendly software interface package to enable non-technical personnel to plan the movement and operation of an AGV in a plant, and then to automatically generate a computer program to execute the plan.

"A Study of Productivity Changes Associated with the use of Ergonomically Designed Chairs in Apparel Manufacturing" Principal Investigator: Dr. Jack Peck
The objective of this contract is to collect hard data from production apparel plants in order to measure the benefits of reduced fatigue through the use of ergonomically designed chairs.

Other Funding:

"Fabrication System for Stitchless Chemical Protective Suit"
Principal Investigator: Dr. Christine W. Jarvis Sponsor: U. S. Army
This research is funded in order to develop new ways of fabricating protective suits for use by combat personnel during chemical warfare. The garment design, materials used, and stringent quality standards make production of large quantities of the chemical protective suit in a reasonable amount of time and at low cost virtually impossible. One potential solution is to utilize different manufacturing techniques for assembling portions of the garment. These techniques include ultrasonic welding, heat fusing, and chemical adhesives.

FEBRUARY 14, 1990

GEORGIA TECH/SOUTHERN TECH

OVERVIEW

(PAPER NOT AVAILABLE)

FEBRUARY 14, 1990

NORTH CAROLINA STATE UNIVERSITY

OVERVIEW

MANUFACTURING TECHNOLOGY FOR APPAREL AUTOMATION: AN OVERVIEW OF THE TASKS PERFORMED UNDER CONTRACT DLA-87-C-0509 at NORTH CAROLINA STATE UNIVERSITY by Trevor Little and Edwin McPherson

INTRODUCTION

The objective of this project is to develop and demonstrate commercially viable apparel automation technology which has the flexibility to quickly change production from civilian to military sewn products (and vica versa) without extensive modification or set-up effort. The contract further insists upon the two critical requirements, that is, commercially viable and a minimum conversion time and effort.

Envisioned for this project were a small number of hardware modules that could be configured, through computer software, physically or a combination of the two, into a variety of work groups, to accommodate a wide range of sewn products. The modules themselves would have functions such as materials handling, joining and/or parts orientation and to the maximum extent practical each module should have a "stand-alone" function which can economically justify its acquisition independently of other modules. The modules were further required to be self-contained to the maximum extent practicable and be quickly and easily be connected to other modules in a work group.

Additionally, the automated work cell and modules should be an attractive investment for apparel manufacturers.

To accomplish the project the tasks were apportioned to five phases initially:

- Phase 1 Project Management
- Phase 2 Review of Garment Subassemblies
- Phase 3 Specification of Modularized Work Unit Groups
- Phase 4 Design, Construction and Testing of Work Unit Groups
- Phase 5 Production Validation

Additional phases have been added since the time of the award to address specific needs of the project or conduct basic research.

- Phase 6 Module 2A Folding Module
- Phase 7 Market Survey
- Phase 8 Analyse and Define Flexibility
- Phase 9 Optimize Flexible Ply Separation

Industrial Review Board

To assist with the project, and Industrial Review Board was established to provide a forum for prioritizing industry needs and assessing industry response. The IRB meets approximately quarterly to review the progress of the project, assess the technical direction and make recommendations based on their industrial experience

Members of the IRB are:

Hubert Blessing	Levi Strauss 1987-1989
Manuel Gaetan	Bobbin-Blenheim
John Nicholson	Tennessee Apparel
Ernst Schramayer	JetSew
Maxwell Tripp	Sunbrand
Jud Early	Haggar Apparel Company
Don Moffett	DPSC
Joe Off	[TC]2
Ed Levell	Consultant
Don O'Brien	DLA
Mahala Langford	[TC]2
NCSU Faculty and Staff	

Previous Related Work

Work previously completed at North Carolina State University and sponsored by the Textile Clothing Technology Corporation, [TC]2, led to the development of an apparel product database of operation sequences for both civilian and military apparel. This database was used to identify candidate operations and target operation sequences for this project on automation.

Selection of Candidate Operation.

The front pocket was identified as the product to be assembled by the automated work cell. The pocket assembly specifications were used in specifying the work cell requirements in terms of part size, target cycle time, target costs etc.
The front pocket assembly offered several challenges for equipment development particularly the combining of three garment parts to make a bagged pocket. To our knowledge , no commercially available work cells exist in the apparel industry for assembly of three component assemblies.

Sub-Contract Award

Ark, Inc. was the successful bidder for the sub-contract as drafted by the Research Administration at North Carolina State University. The contract called upon Ark, Inc to design and construct at least four basic cloth handling units, or modules, and combine them to form an automated work cell.

The conceptual design as presented by Ark, Inc. is shown in Figure 1.

The Turn and Divide Module is designed to take face-to-face cut stacks and separate the stack into rights and lefts for subsequent automated operations.

The Serger Module is designed to automatically feed, serge and stack small parts such as pocket facings and bearers

The Asembly Module is designed to feed, register, combine and join small parts such as front facing with the pocket lining.

The subassembly is then stacked for transfer into the fourth module called the "Bagger Module". The Bagger Module is designed to feed, register, fold, form the pocket "bag" and stack the subassembly.

Figure 2 shows the building blocks or individual devices used to reduce the complexity of the total system.

Current Status of Each Module

The short video of the three modules completed to date shows the status of each mod le and how the conceptual design has been implemented in hardware and software.

The Turn and Divide Module will shortly be shipped to DPSC in Philadelphia to undergo a 3 month trial in the cutting room.

The Serger Module is being shipped to Kellwood Company, Sportswear Division where it will be plant tested on styles being produced for Mervyn's.

The Assembly Module is in the Development Stage at Ark, Inc.

The Bagger is in the Design Stage at Ark, Inc.

Some Development Issues

1. The current specifications for assembly of BDU and Military Dress trousers permit 64 ways of constructing front pocket assemblies. Considerable discussion was needed to decide how the automated work cell would "standardize" the construction.

2. Off-the-shelf apparel equipment is not designed to become an integral part of an automated work cell. For example, the Juki Model ASN1000B, small parts serger just introduced to the US market was incorporated into the Serger Module. Since the machines' control system was designed for manual operation there was excessive delay between the parts being fed to the machine and activation of sewing. The control system required modification to activate the sewing head quickly once the part triggered the photocell upon arrival at the sewing module.

3. The search for an off-the-shelf feeder module led to the design and development of a "rod-feeder" for pick-up and transporting parts from a cut stack. More recent developments show that the rod feeder can replace the Turn and Divide module for some applications leaving the Turn and Divide machine as a stand-alone unit. The rod feeder has Patent Pending status in the Patent Office.

4. The Beisler Model 2111/1 semi-automatic pocket facing machine have their own controllers and are used on the Assembly Module. Integration of the modules has created some 158 I/Os for the controller of that module leading to the need for greater reliability in each stage of the process.

Other Phases of the Project

Phase 2 Review of Garment Subassemblies

This Phase has resulted in a database of operation sequences for some 400 apparel products. A description of the database is given in Apparel Manufacturer May 1989, P81-83; Consider your Options by Carol Carrere. This information is available on a Service Request Basis and can assist manufacturers in their cost modelling of garment styles, comparison of garments for construction similarities, grouping of products for equipment selection, etc

Phase 7 Conduct Market Survey

As the project developed, it became necessary to conduct a Market Survey to assess the size of the potential market and to provide direction on the commercialization of the technology. The Phase is in the data collection stage.

Phase 9 Optimize Ply Separation

Although it was decided early in the project that the Clupicker was an appropriate ply separating system, the need to change the Clupicker setting, [gap setting, contact pressure] for different fabrics was desirable. This Phase conducted some basic research leading to several recommendations for modifications that allow the Clupicker to be adjusted rapidly and reliably when different materials are being processed.

Phase 8 Analyse and Define Flexibility

Apparel manufacturers require more flexibility in their manufacturing operations than ever before to cope with style variation and processing of smaller cut lots. This Phase is in the process of analyzing how to incorporate the needed flexibility into apparel assembly equipment so that equipment developers can take this int. onsideration when designing new machinery.

SUMMARY

This DLA Contract has led to many important and exciting developments that provide immediate benefit to the Apparel Industry. These include:

a. An improved ply separation system capable of accommodating a wider range of fabrics and being adjusted more reliably and quickly.

b. A stand-alone Turn and Divide Machine for use in the cutting room or area for splitting apart the bundles.

c. A multi-purpose automatic serger for small parts serging that can be used for a wide variety of apparel products

d. An Assembly Module that illustrate the automated handling and sewing of three components: all component modules capable of working simultaneously.

e. A data base of operation sequences that has general applicability for the apparel industry and equipment developers.

f. An improved automated pocket bagger.

g. A new way of ply separating and delivering cut parts to the sewing head in the form of a rod-feeder.

h. An improved, economical XYO orienting device for incorporating into automated work cells.

i. New ways of analyzing the benefits to be gained and ways of justifying the investment in automated technology.

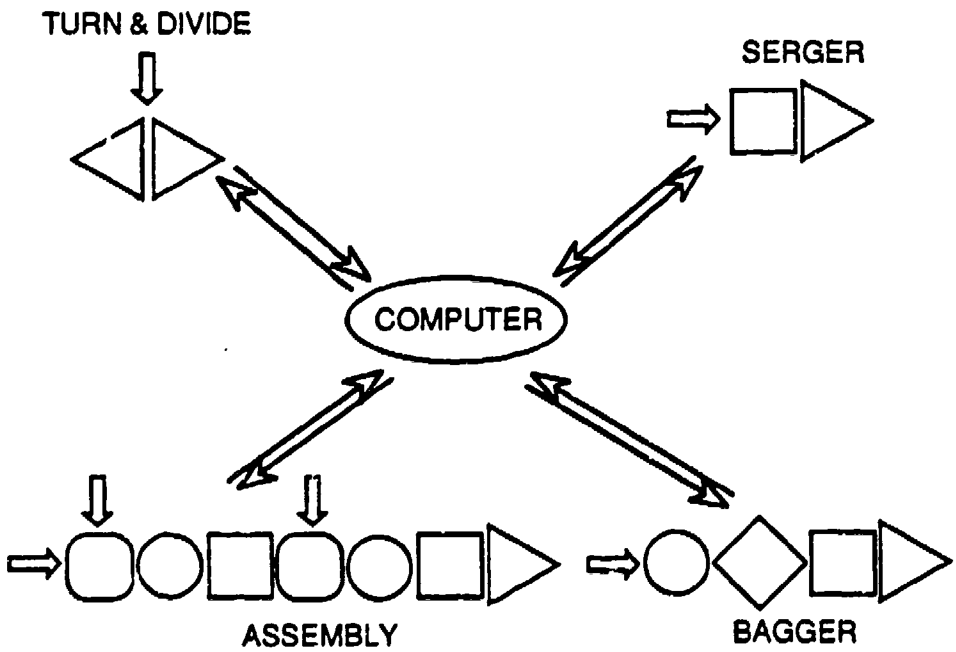


Figure 1: Conceptual work cell design

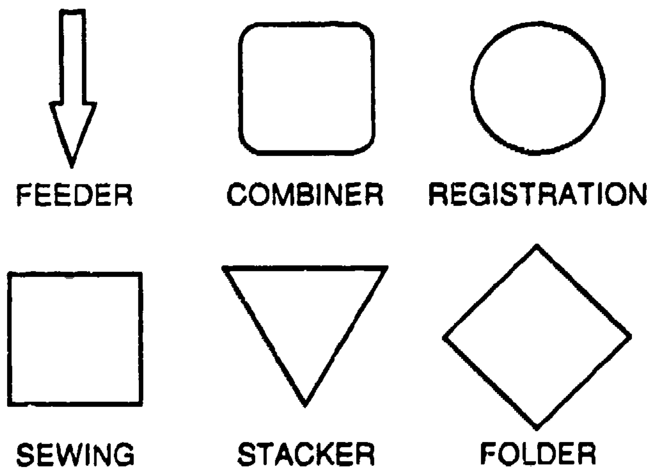


Figure 2: Work cell "building blocks"

FEBRUARY 14, 1990

UNIVERSITY OF SOUTHWESTERN LOUISIANA

OVERVIEW

(PAPER NOT AVAILABLE)

FEBRUARY 14, 1990

PHILADELPHIA COLLEGE OF TEXTILES AND SCIENCE

MECHANICAL PROPERTIES OF FABRICS

(PAPER NOT AVAILABLE)

FEBRUARY 14, 1990

DLA PERSPECTIVE

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

TEXTILE/CLOTHING TECHNOLOGY CORPORATION

SIMULATION

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

GEORGIA TECH

DISCRETE EVENT SIMULATION

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

UNIVERSITY OF SOUTHWESTERN LOUISIANA

LOOK AHEAD SIMULATION

Look–Ahead Simulation of Shop–Floor Operations

DLA900–87–D–0017 Task No. 0003

Clemson University
J.C. Peck, R.P. Pargas,
P.K. Khambekar, S.K. Dharmaraj

University of Southwestern Louisiana
L.M. Delcambre, S. Landry, J. Waramahaputi

CLEMSON UNIVERSITY

OUTLINE

Objectives

Performance Metrics

Uniprocessor System

Multiprocessor System

Schedule

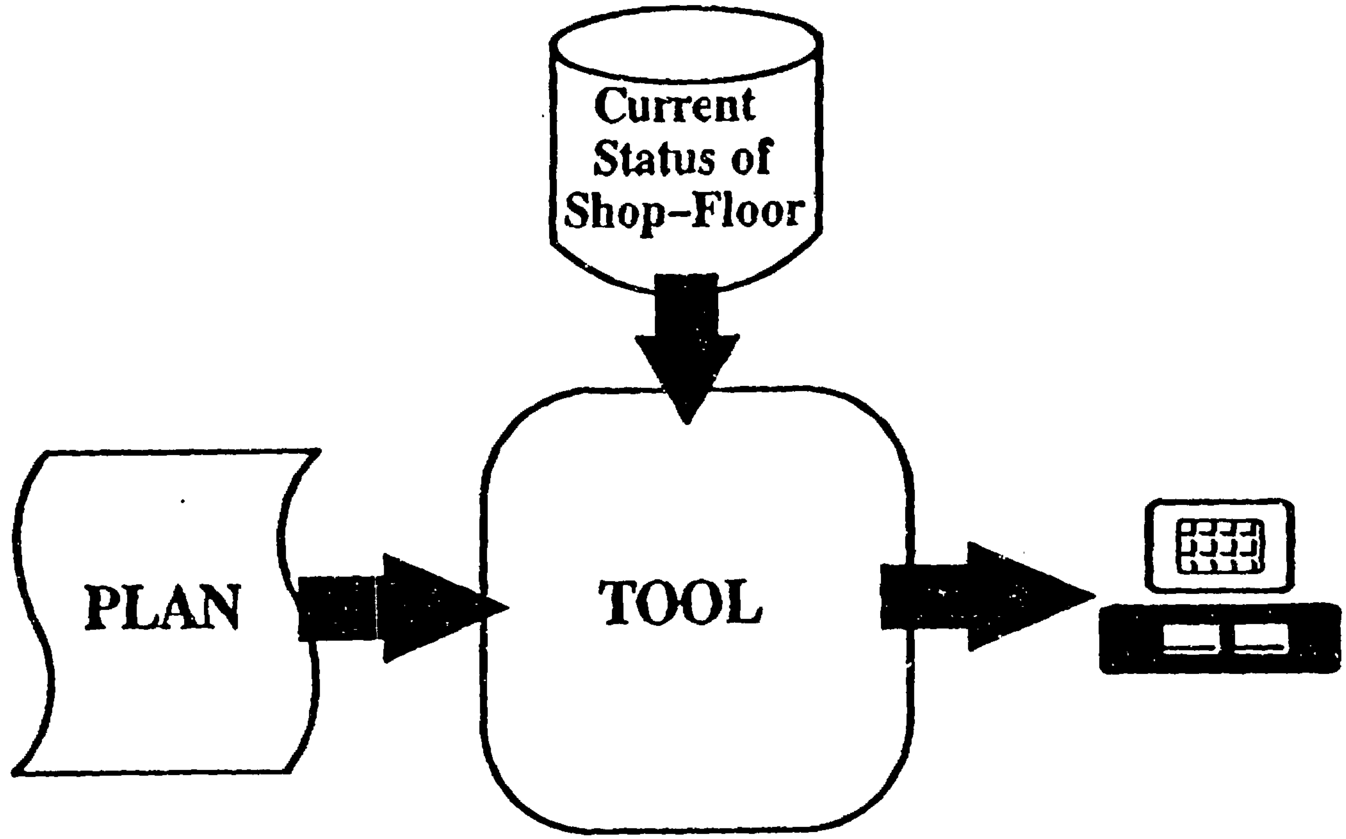
OBJECTIVE

Develop a tool that provides the shop–floor supervisor with timely information and fine–tuned control over daily operation

This tool should:

- Accurately model the manufacturing process
- Graphically present the user with a rich set of performance metrics
- Respond quickly
- Be evaluated in one or more apparel plants

OBJECTIVE



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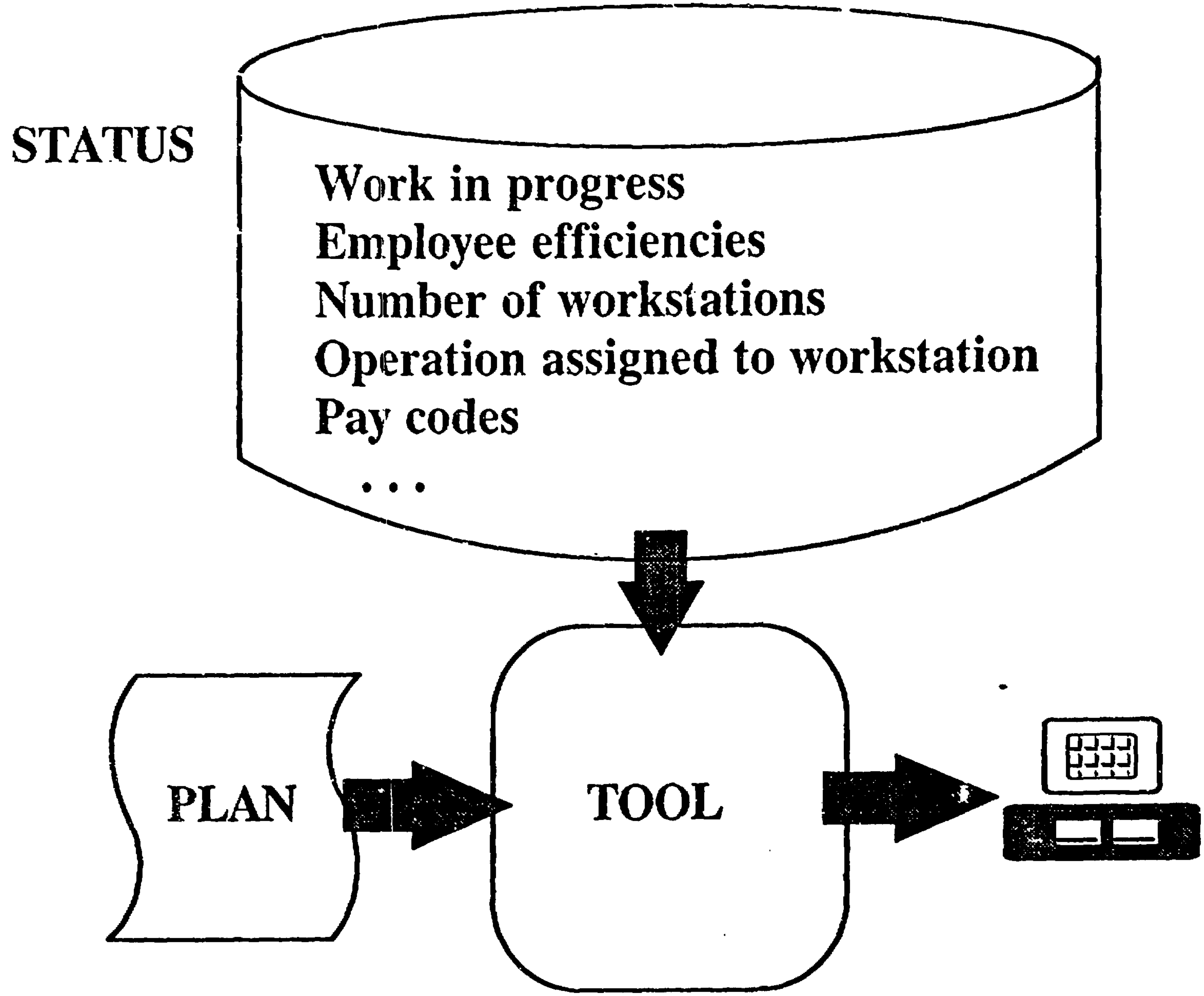
Look-Ahead Simulation



CLEMSON UNIVERSITY

Look–Ahead Simulation

PLAN

8:00 Assign Joan to Workstation A
Assign Jill to Workstation B

. . .

8:30 Put Suzy on training, Workstation D

9:00 Take Pat off training

9:30 United Fund meeting

. . .

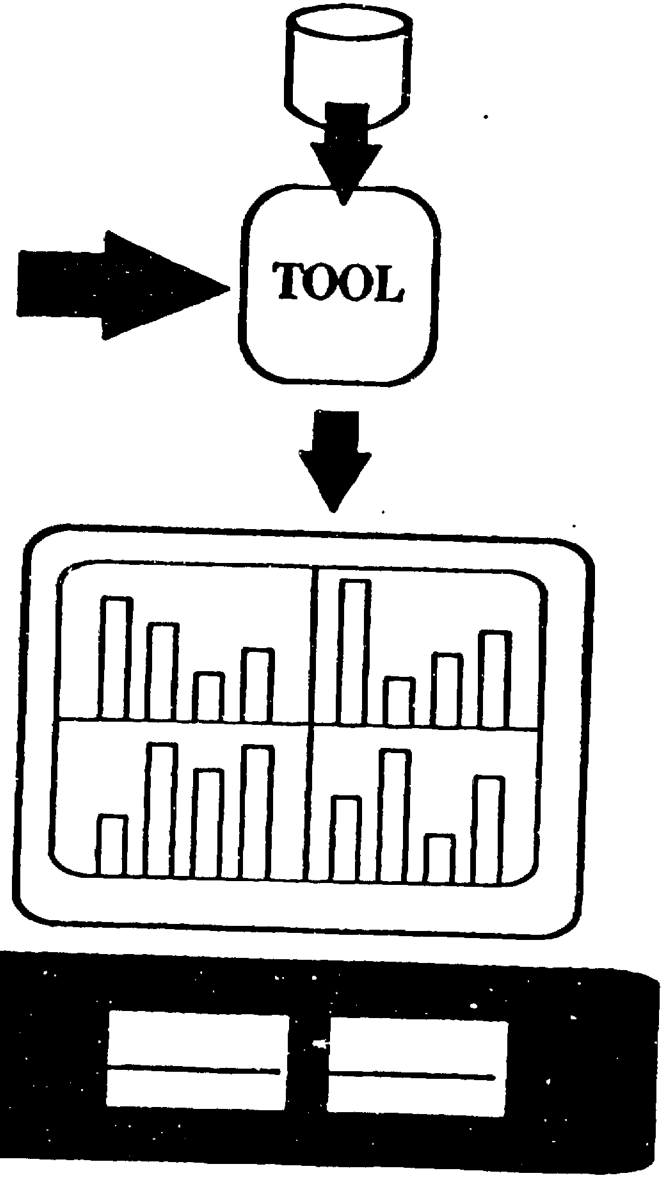
10:30 Cut #123 arrives, priority 9

. . .

11:00 Move Joan to Workstation C

. . .

OBJECTIVE



CLEMSON UNIVERSITY

Look–Ahead Simulation

PLAN

8:00 Assign Joan to Workstation A
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. . .

8:30 Put Suzy on training, Workstation D

9:00 Take Pat off training
9:30 United Fund meeting

. . .

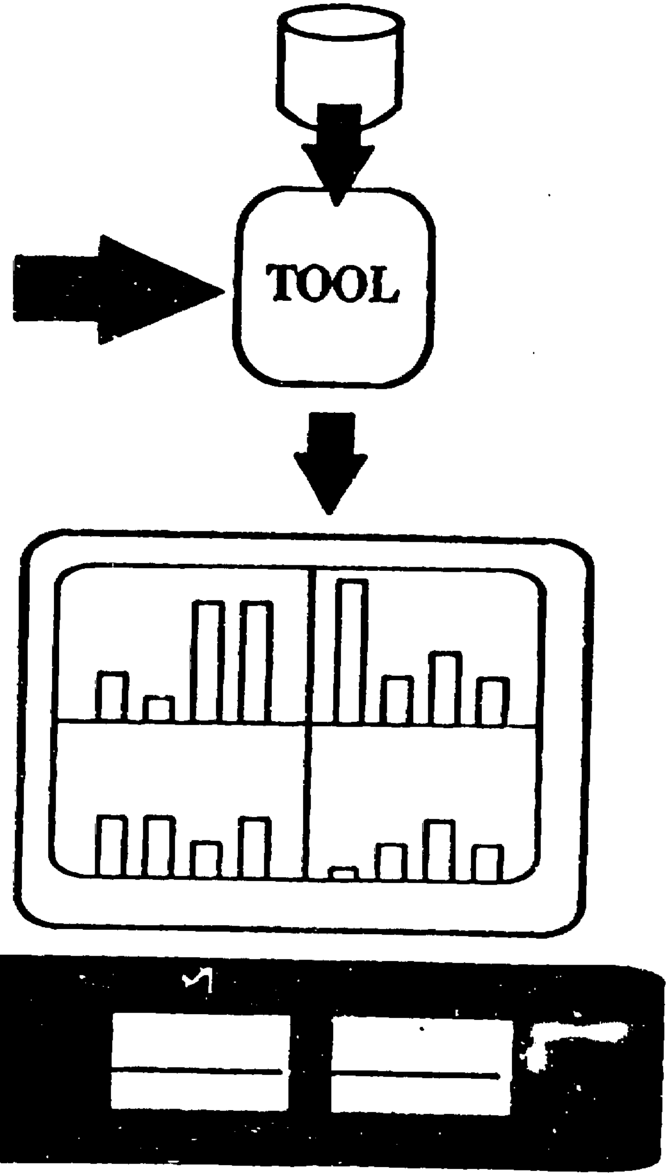
10:30 Cut #123 arrives, priority 9

. . .

11:00 Suzy times out
Move Joan to Workstation D
Move Mary to Workstation A
Move Jill to Workstation C

. . .

OBJECTIVE



CLEMSON UNIVERSITY

Look–Ahead Simulation

PLAN

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Move Joan to Workstation C
Move Mary to Workstation A
Put Jill on training

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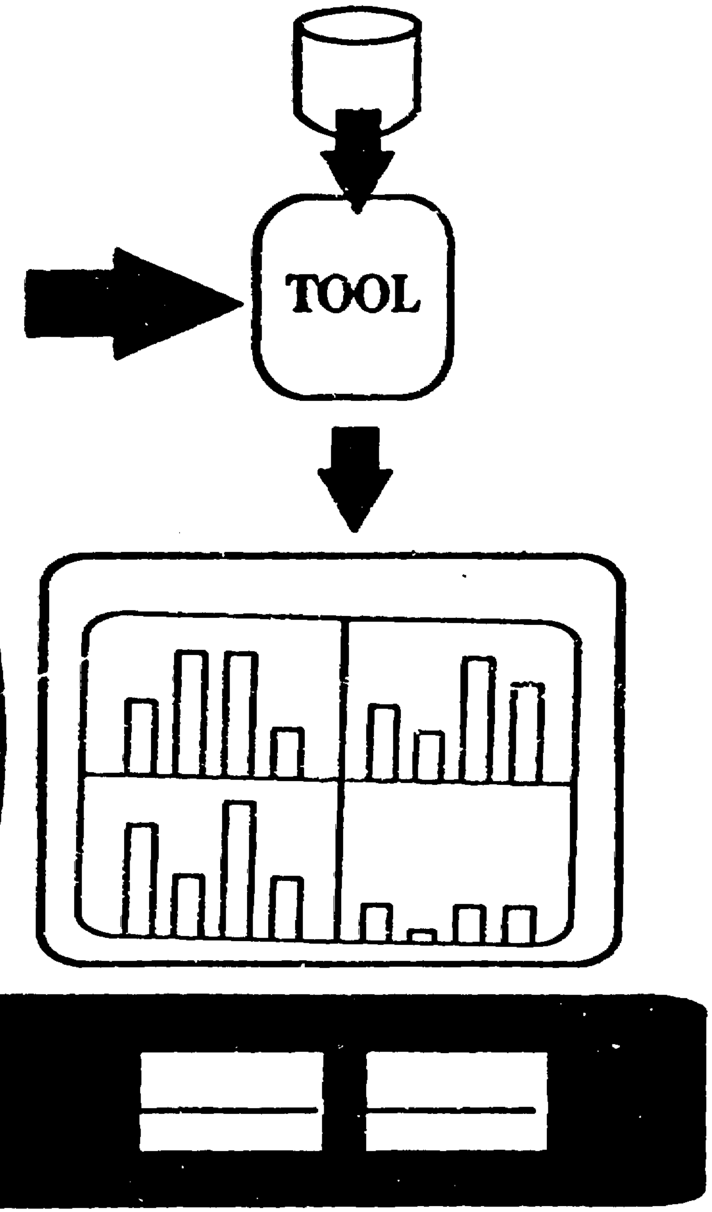

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Look-Ahead Simulation

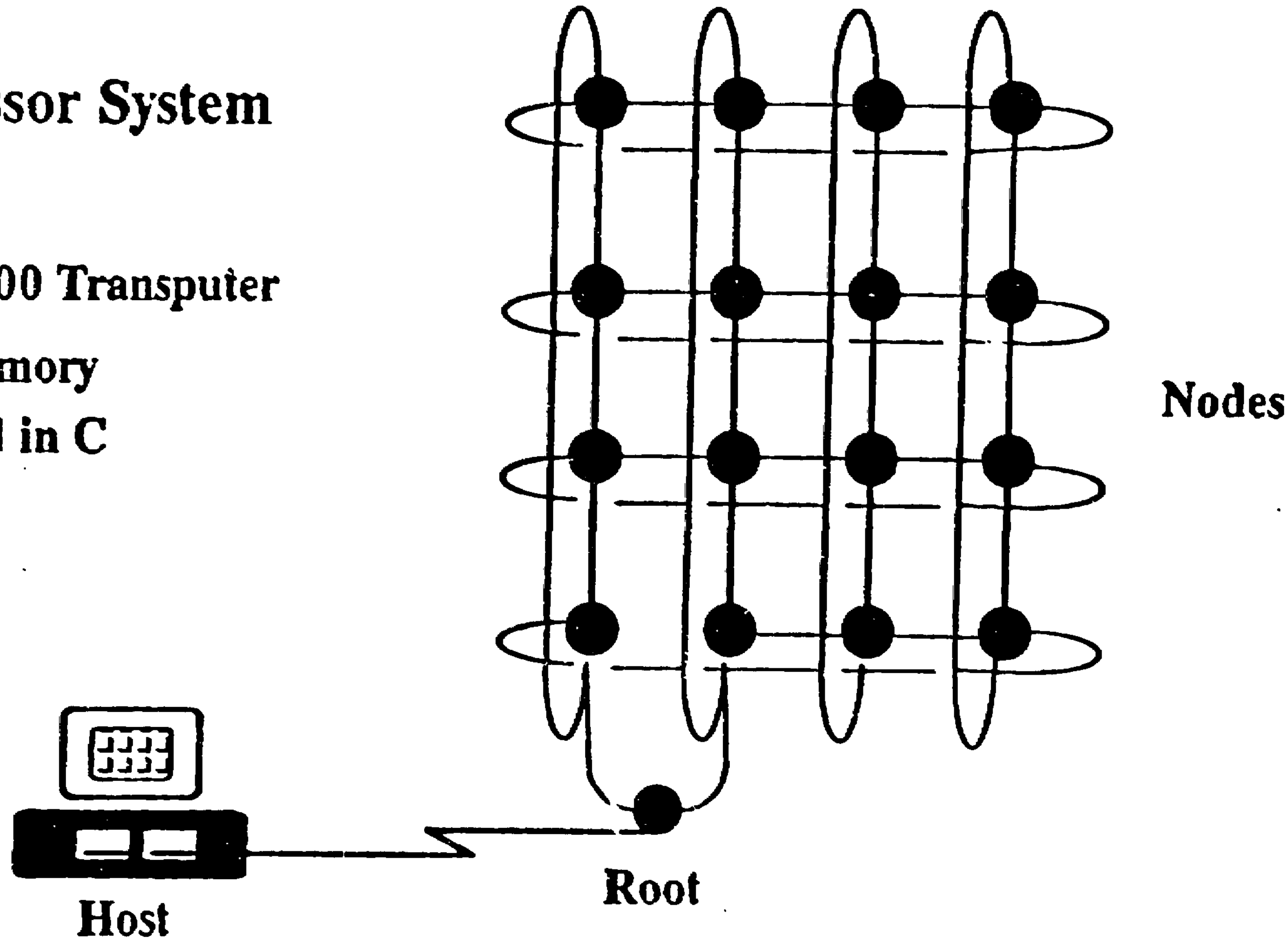
PERFORMANCE METRICS

- Performance measured at Cut, Style and Plant level
- Metrics obtained for a user-defined period
- Classification

  Cost
  Waiting time
  Flow time
  Lateness
  Machine utilization
  Labor utilization
  Production
  Efficiency

Multiprocessor System

- 17 nodes
- INMOS T-800 Transputer
- 2-Mbyte memory
- Programmed in C



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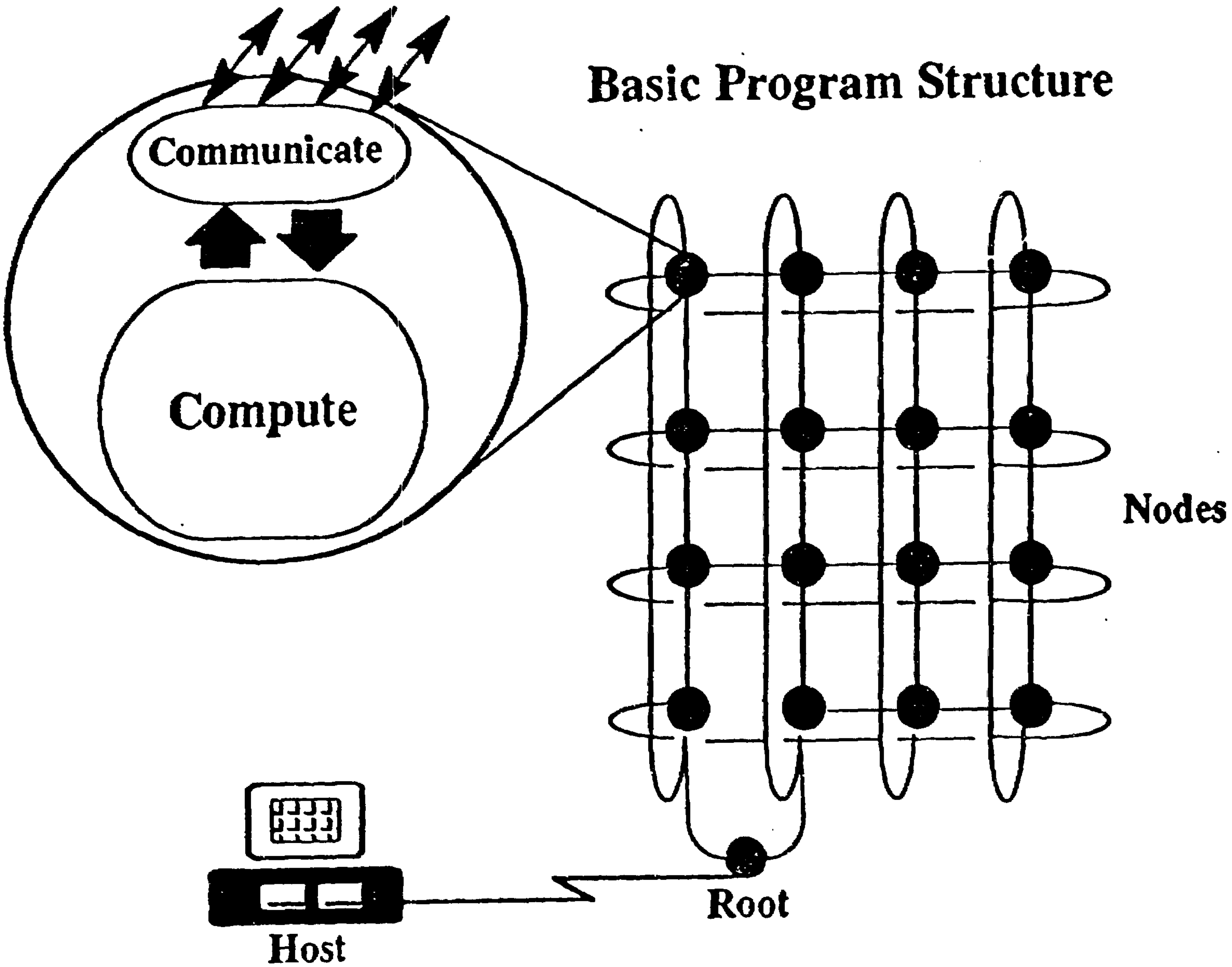
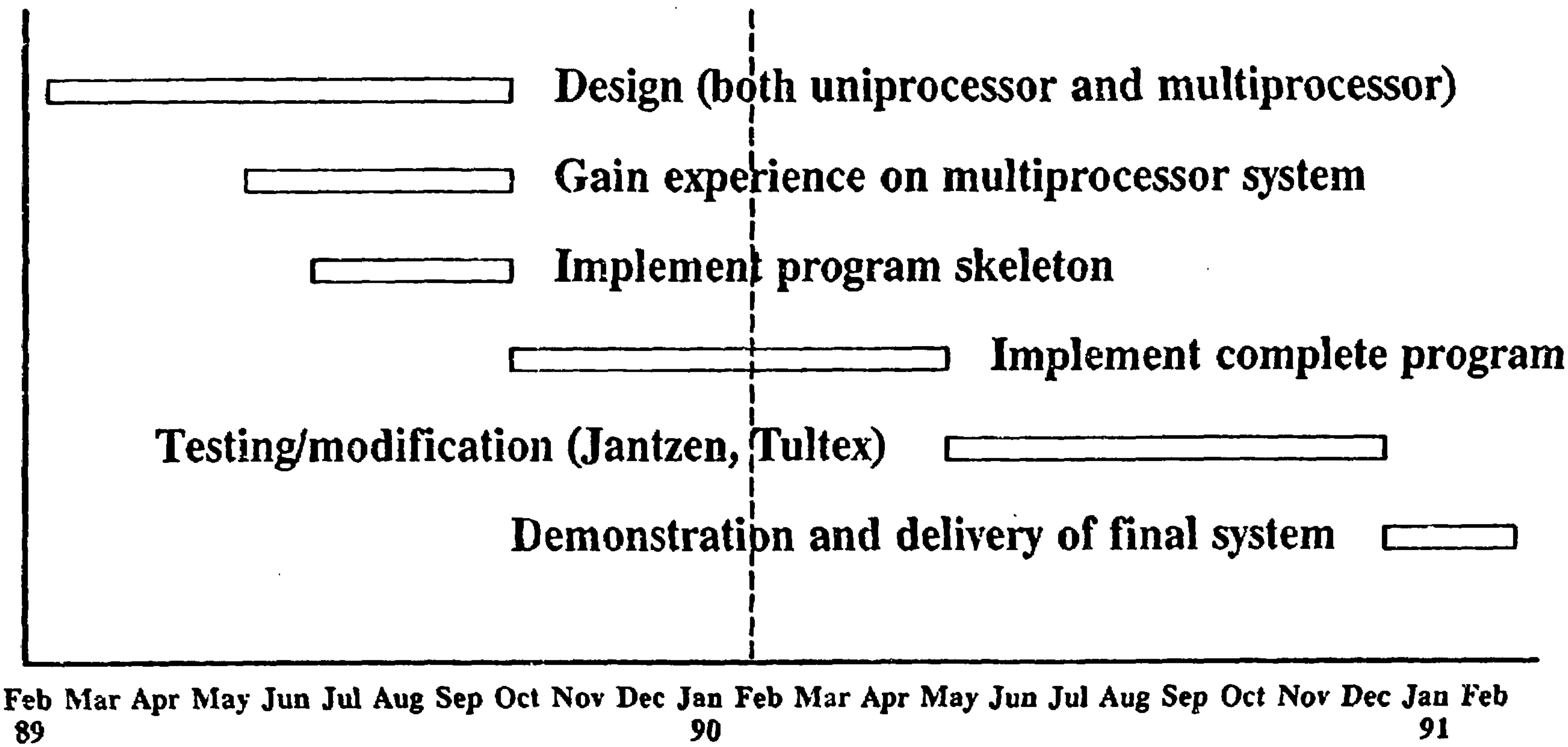
Look Ahead Simulation

Basic Program Structure



Look Ahead Simulation

SCHEDULE


Design (both uniprocessor and multiprocessor)
Gain experience on multiprocessor system
Implement program skeleton
Implement complete program
Testing/modification (Jantzen, Tultex)
Demonstration and delivery of final system
Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb
89
90
91

Production Scheduling Through Distributed Simulation

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Clemson, SC 29634-1906

Extended Abstract

Clemson University holds a contract with the Defense Logistics Agency to help improve the competitiveness of the US apparel industry through the use of advanced manufacturing technology and associated management techniques. As part of this contract, $1,500,000 each year is available for research projects intended to improve the productivity of apparel equipment and personnel. The authors of this paper, in cooperation with researchers at the University of Southwestern Louisiana, are engaged in one of several such research projects to develop a simulation software tool intended to assist middle to high level management in planning and scheduling work, personnel, and machines in the "near" term. The near term could be the next week, next day or next hour, depending on the frequency of use of the software tool.

Apparel plants who have scheduling problems operate on a larger scale than manufacturing plants in many other industries. A typical apparel plant of this type would have more than 400 direct labor (incentive) employees with perhaps 500 machines (some large plants have 1500+ employees). Both employees and machines are capable of performing multiple operations, but only a small percentage of the total operations required to manufacture a particular garment. Active on the shop floor at

any one time might be 100 or more production lots (orders) each consisting of perhaps 200 bundles of garment parts, each consisting of 5 or more subassemblies, each requiring 1 to 20 operations. Production lots are possibly of different styles, meaning the operations and sequencing of operations are different. Bundle subassemblies flow through the manufacturing process in parallel and join (merge), as operations are completed, to produce finished garments. The matching of subassemblies from parent bundles is important since color shading variations will be noticeable otherwise. Since employees and machines have multiple, but limited, skills and capabilities, load balancing of these resources against required work is a major problem.

Since the ultimate goal in production scheduling is to improve the operation of a plant, the first question which must be asked is "How do you know if a change in an operational plan produces a better or worse schedule?" The performance goals of management, and at different plants at different points in time, might produce drastically different answers to the question. At one point in time, the goal might to be maximize the output of size 16/34 red button-down collar shirts while at another time it might be to minimize the work-in-process inventory level subject to keeping the average efficiency of employees above 95%. In fact, the answer might change if management knew the optimization limits on the scheduling goals they might pick! The point of this discussion is that in general, one cannot always predefine an objective function for optimization. The process of measuring performance, while working toward optimizing any objective function, might change the function. This is a

variation of what the physicists call the Heisenberg Uncertainty Principle or what the industial engineers call the Hawthorne Principle. The process of measuring an entity changes the behavior of the entity being measured.

The first step taken in this research project was to interview numerous plant managers concerning goals to produce a set of performance metrics representing a wide class of objective functions for optimization. This set currently contains about 75 metrics which relate to the performance of the plant, each department, each lot and each style in-process. Employee performance employee pay, standard minutes produced, progress of specific work units, excess costs, lateness of orders and work-in-process inventory levels are but a few of the variables measured. This set of performance metrics is maintained during the execution of the simulator and displayed dynamically in the form of graphs as the values change. Multiple windows allow the simulator user to monitor any collection of metrics (subject to screen size limitations) as the simulation progresses.

The approach taken by many simulations is to use statistical distributions to approximate variables such as job arrival and service time as well as employee efficiency, etc. The primary reason for this approach is that no real data is available to provide accurate values for these variables. The approach taken in this simulation is to use the large volume of data produced by a real-time shop floor control system (marketed by Foxfire Technologies Corporation and installed in several apparel plants

in the US), which represents the current state of the apparel plant, to define the current state of the simulation. This real-time system collects data through use of a device at each workstation concerning employees, lots, bundles, subassemblies, and operation as work progresses through the plant.

The operation of the simulator is as follows. The simulation operator will define a plan for operation of the plant in the near term (see above). The starting point for the plan is the current state of plant as represented by data contained in the real-time system. The operator then specifies changes to the plan which he wishes to implement at given times. New work might arrive at mid morning, personnel might be reassigned to different operations at specified times, machines might be taken out of service for preventive maintenance, new machines which operate at greater speeds might be placed into (simulated) service, etc. With this new plan for operation (usually a small variation in the real plan currently in effect) the simulation will begin execution. The operator can request that the plant be simulated until a specified point in time, for a specified duration or until an interrupt key is pressed. During this period of time the graphical display of performance metrics will be dynamically updated. If the operator is unhappy with the values of certain metrics, he might choose to "rollback" the simulation to a specified point in time and rerun with a new plan. By this interactive and iterative technique, a plan which best suits management can be developed. This plan can then be printed and used as an order (or recommendation) to shop floor

supervisory personnel. Monitoring of the actual shop floor performance is already provided as part of the Foxfire system.

The primary objective, therefore, is to allow the user to develop a production scheduling plan interactively, in the same manner as one works with a spreadsheet program. In a spreadsheet, the user can change a single cell, and every other cell whose value depends upon it changes automatically. The user can immediately see the "bottom line" result of his single change. The user of this simulation will be able to enjoy the same capability, i.e., to be able to change one part of his current production plan (say, replace Mary with Suzi on Machine A at 10:00 a.m.) and be able to see, very quickly, the effect of the change on overall production. The information the user receives will be the metric information he has selected to view. If he is happy with the new results, the user may opt to keep the employee change in his plan. Otherwise, he may delete the change and continue try other modifications to his plan.

A major concern in this simulation, however, is computer response time. A simulation of a large apparel manufacturing plant with 500 or more workstations is anticipated to require much more computing power than is available on a PC, even on the latest models such as the IBM PS/2 family, some of which use the very fast Intel 80386/387 processors. For this reason, the simulation is being developed on a distributed memory multiprocessor system. The multiprocessor consists of seventeen INMOS T-800 processors, called Transputers. Each Transputer has two Mbytes of memory and is

slightly more powerful than an Intel 80386/387. Acting as a front-end processor which accepts input from, and provides graphics output to the user, is a standard PC, a COMPAQ Deskpro 386/25. The design calls for the simulation to execute entirely on sixteen of the seventeen Transputers. The results are collected by the seventeenth Transputer and sent to the PC for graphical display. Such a system should be able to deliver the speed necessary to make this simulation useful.

The decision to develop a distributed simulation created two new problems which do not exist on single processor implementations. The first results from the fact that each processor is working asynchronously with its own logical clock. The processors communicate with each other by passing messages. Each of these messages carries a time-stamp, the simulated time at which the information in the message was generated. If a processor gets too far ahead in simulated time, it is possible that it will receive a message from another processor in the (simulated) past. Had the processor received the message earlier, the simulation within this processor may have proceeded differently. The result, of course, is a potentially incorrect simulation.

Several solutions to the synchronization problem in distributed simulations have been proposed in the literature. One class of solutions, called conservative or pessimistic, allows each processor to proceed only when it is guaranteed that there is no possibility of receiving a message out of time-stamp order. One specific algorithm suggests that processors generate and send nu'' or empty, messages which carry nothing more than a

time-stamp. The purpose is simply to broadcast each processor's current time to other processors. Although this does solve the problem, it also clogs the communication links with numerous null messages, eventually choking the system. Another class of solutions, called optimistic, suggests that processors operate as fast as they can without regard to synchronization. Should one processor receive a message out of time-stamp order, it initiates a process of "rolling-back" the simulation to a point where all processors are again in synch. Once in synch, processors again proceed independently. The drawback with this approach is, of course, the complications which arise when the program tries to undo a sequence of events and to restore the state at some earlier time. The approach implemented in this simulation is between the optimistic and the pessimistic solutions. Null messages are sent, but only on demand. If Processor A cannot proceed because it is unsure of the current simulated time of Processor B, it sends a request to B. Processor B will respond by sending a null message to A containing B's current time. With the new information, A can then proceed.

A second problem is that of load balancing. The ideal in a multiprocessor system is to balance the computational load evenly among all processors. This load, of course, is dynamic and cannot be predicted accurately. Effort must be made, therefore, as the simulation is running to monitor how much computation is actually done by each processor. When imbalance is detected, the simulation self-corrects, i.e., simulation

workstations and buffers are sent from one processor to another thereby reducing the computation load of one processor and increasing the load of another.

The simulation is, at present, approximately fifty percent complete. The project is anticipated to be completed by May, 1990 at which time test versions will be installed at two apparel plants, Tultex in Martinsville, Virginia and Jantzen in Seneca, South Carolina. Testing and modification should take approximately eight months, with a final version complete by December, 1990.

FEBRUARY 15, 1990

FASHION INSTITUTE OF TECHNOLOGY

SUPERVISORY TRAINING

A COMPREHENSIVE SUPERVISOR DEVELOPMENT PROGRAM

A SHORT TERM RESEARCH & DEVELOPMENT PROJECT

by
THE FASHION INSTITUTE OF TECHNOLOGY
ADVANCED APPAREL MANUFACTURING TECHNOLOGY
DEMONSTRATION CENTER

Presented at
the Advanced Apparel Manufacturing Technology Conference

Feb. 15, 1990
Philadelphia, PA

by
Dr. Frederick Golden
Investigator

OVERVIEW
COMPREHENSIVE SUPERVISOR DEVELOPMENT PROGRAM

Since first line supervisors have a key role in the successful use of advanced manufacturing technology, a short term task was assigned to F.I.T. to develop a Supervisor Training Program.

The objective of this project is consistent with the overall efforts of the AAMTD to increase the use of advanced manufacturing technology and systems in the domestic U.S. apparel industry.

The scope of the project includes:

- A survey of existing public and private programs, with special attention to utilization of advanced/automated manufacturing technology in the apparel industry.

- Create a supervisor training program which addresses this use of advanced equipment and systems.

- Field test the supervisor training program for use in the apparel industry.

Among the general topics to be covered are:

- Teaching and learning considerations in the advanced manufacturing technology environment.

- Goal setting and performance objective strategies for the supervisor.

- Training of current employees to adapt to, and function in, the advanced/automated manufacturing environment.

- Psychological and sensitivity requirements for the supervisor in the advanced manufacturing technology environment.

OVERVIEW OF WORK ACCOMPLISHED TO DATE

Tasks which have been completed to date include:

- A comprehensive survey of apparel manufacturers to determine content of programs in place, subjects perceived to be needed in a supervisor program, and reasons for failure of previous programs.

  Approximately 36 surveys were returned covering more than 50,000 employees and 2,300 supervisors. The results have been summarized and evaluated.

- Visits to apparel manufacturers.

One company in particular considers its program covering both behavioral aspects and technology as a competitive advantage. However, the technical program does not comprehensively deal directly with utilization of advanced technology.

In another site visit, the effect of cultural and language differences was observed, particularly between supervisor and operators.

- Machine and equipment suppliers were interviewed for identification of roadblocks to adoption of new advanced technology and techniques applied to attain successful utilization of their new advanced technologies.

- Directors of R&D divisions of apparel manufacturers also were interviewed to obtain insights on the role of supervisors in utilizing new advanced equipment they develop or sponsor.

- Companies outside the apparel industry were visited or researched for ideas from their supervisor training programs.

- A literature search was completed

- Commercially available training programs have been researched. The search for appropriate programs is continuous.

- A supervisory training program undertaken for a large tailored clothing factory was observed, in which the interpersonal skills requirements were manifested.

SOME TENTATIVE CONCLUSIONS

Among the conclusions which have emerged so far:

1. Many companies recognize the need for pre-training prior to appointing people as supervisors.

2. Most of the survey respondents stressed their need for supervisory training in interpersonal relationships.

3. As often observed and seldom practiced, careful selection of supervisors is required.

4. Supervisors must be prepared to play a role in the evaluation and selection of advanced technology.

5. The effect of cultural and language differences which were observed, points to a special requirement for dealing with this difficult subject.

6. The supervisor program under development requires a knowledge of basic operations as a foundation to understanding how advanced equipment can be utilized effectively. The planned program will include, from the technical point:

   - Basic stitch and seam formation
   - An overview of basic concepts of advanced equipment, such as electronics, pneumatics, and other principles of operations of concern to a supervisor.
   - Operations adjustments
   - How to detect malfunctions and to deal with them. (what to question)
   - Methods
   - Work flow
   - Safety
   - Economics of the investment-productivity, costs, machine efficiencies (utilization).
   - Ergonomics

7. Interpersonal or behavioral skills to be taught include:

   - Basic training skills
   - Introduction of new equipment to operators, including re-training techniques.
   - Overcoming objections.
   - Attitudes and acceptance of change.
   - Dealing with cultural differences and language problems.
   - Group/team development

- Role of engineering plant and top management.

8. The investigators have been cautious in identifying genuine need and in avoidance of "re-invention", prior to preparing the actual training programs. Connections to other projects underway have been sought and identified. For example:

   - The study of equipment that has been discarded or underused by apparel manufacturers, will reveal causes for unsuccessful utilization of advanced technology which must be addressed by a supervisor training program.

   - Studies of modular manufacturing systems and unit production systems signal the changing role of the supervisor in those situations which must be considered in the training program.

   - The Georgia Tech study of ergonomics and its planned supervisor training program suggested collaboration on this subject.

   - The possible use of "knowledge-based" systems concepts to extract the processes which successful, experienced supervisors use in making judgments have been investigated, especially in connection with acceptable quality of production from advanced equipment. Questioning procedures used by Georgia Tech in their approach to knowledge-based systems are informative for this purpose.

FEBRUARY 15, 1990

GEORGIA TECH

ERGONOMICS FOR THE APPAREL SUPERVISOR

DESIGN AND DEVELOPMENT OF A SELF STUDY COURSE FOR APPAREL SUPERVISORS IN THE PRACTICAL APPLICATION OF ERGONOMIC PRINCIPLES

PHASE 1 REPORT: ERGONOMIC CONSIDERATIONS IN CONVENTIONAL TROUSER MANUFACTURING

Research Sponsored by:

U.S. DEFENSE LOGISTICS AGENCY

Principal Investigator: Daniel J. Ortiz
Principal Investigator: Michael J. Kelly, Ph. D.
Research Investigator: Theodore K. Courtney
Research Investigator: Dennis J. Folds, Ph. D.

Georgia Tech Project #: A-8311

Georgia Institute of Technology
Georgia Tech Research Institute
Economic Development Laboratory
(404) 894-8277

March 1989 - September 1989

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TABLES AND FIGURES

ABSTRACT

In order for the apparel industry to maintain and improve its competitiveness in the world marketplace, it must adopt many emerging technologies and achieve the maximum benefit from them. During the transition to a high technology manufacturing environment, jobs and workplaces should be designed to promote employee productivity, comfort and safety. Design of jobs and equipment to match the physical and mental characteristics and limitations of the equipment operators is the goal of the science of ergonomics.

Georgia Tech is conducting a two-year program to explore ergonomics issues in typical trouser manufacturing plants in the Southeast, to test cost-effective solutions to these problems, to predict and address ergonomics issues in the high technology apparel manufacturing environment, and to develop training and reference materials that will allow plant managers and supervisors to solve basic ergonomics problems on their own.

During Phase 1 of the program, interviews were conducted with over 120 operators in three typical trouser manufacturing plants in the Southeast. These interviews covered work-related injuries and musculoskeletal discomfort, job and workstation design, training, work schedule, and other job factors. A set of relevant body measures was taken of this group of workers. Measures of lighting, noise and temperature were made at sewing workstations in the three plants. Videotapes were made of skilled and novice workers performing certain key operations for later motion analysis.

This report provides a summary of the findings of these investigations including comparisons of the anthropometric data with other available data bases, summaries of the data on musculoskeletal discomfort and implications of the identified patterns, discussions of the physical working environment, descriptions of operator training methods, and recommendations for workstation and job improvement. A discussion of preliminary findings concerning applications of advanced manufacturing technology is also included.

1. BACKGROUND AND OBJECTIVES

In order for the United States apparel industry to maintain and improve its competitiveness in the world marketplace, it must adopt emerging manufacturing technologies and achieve the maximum benefit from them. During the transition to a high technology manufacturing environment, jobs and workplaces should be designed to promote employee productivity, comfort and safety.

Ergonomics (the study of the physical and mental characteristics and limitations of workers and the design of jobs and equipment to take these factors into account) has been effectively applied in many working environments. These include transportation, health care, mining, textile manufacturing, and a host of others. For various reasons, the practice of ergonomics or, alternatively, human factors engineering, has not been extensively applied in the apparel manufacturing environment.

Under the two-year program, Georgia Tech is exploring human factors problems in typical trouser manufacturing plants in the Southeastern United States and identifying and testing cost-effective interventions for the uncovered problems. Lessons learned from this initial exploration will be used to predict and address related human factors issues in the apparel factory of the future as represented by the Apparel Manufacturing Technology Center. In the final phase of the program, training documentation will be produced to assist supervisors, middle and upper management in recognizing and solving typical human factors problems.

Trouser manufacturing, whether in a conventional or high-technology workplace, is a highly labor-intensive process with 20 or more distinct steps. Each of these steps involves the operation of one or more kinds of power equipment such as specialized cutting and sewing machines. The steps require significant amounts of manual manipulation of fabric bundles, individual pieces, and unfinished garments as they are transported, inserted into, and guided through the machines. The operations are highly repetitive and visually demanding.

Repetitive, hand-intensive work may result in health problems such as cumulative trauma disorders (CTDs) that increase absenteeism and reduce productivity. One such disorder is carpal tunnel syndrome (CTS), a compression neuropathy involving the median nerve that provides sensation to a large portion of the hand. Occupational risk factors associated with CTS include repetitive movement of the hand, non-neutral wrist postures, and forceful exertions. The disease is characterized by pain and numbness in the hand and wrist, and it has been found to be common among manufacturing workers.

The objective of the initial phase of the project, on which this report is based, was to collect anthropometric and background data on existing conventional manufacturing workplaces and worker populations. In support of this effort, an extensive literature review was conducted. Literature consulted for this phase has been combined into a reference bibliography in Appendix A. Our interviews and measures were specifically designed to elicit information valuable for (1) identifying and solving current, conventional manufacturing problems, (2) identifying areas of the conventional environment that should be candidates for automation, and (3) predicting human factors related issues likely to appear in the advanced manufacturing environment.

The principal objective of this program is to develop a comprehensive set of specially tailored ergonomics training and reference materials that will help apparel manufacturing supervisors and management (1) identify workplace tools, layouts, and procedures that are incompatible with the characteristics and limitations of the workforce, (2) identify options for addressing the identified problems, and (3) choose and implement ergonomically appropriate solutions. The materials will

specifically address ergonomic aspects of conventional and advanced manufacturing environments in which trousers are produced.

Careful design of workplace tools and equipment requires the engineer to obtain and apply data on the relevant physical dimensions of the worker population. Such data, however, are not readily available for most populations. A decade ago, Van Cott (1980), an ergonomist with the National Bureau of Standards, lamented that "civilian anthropometry data bases in the United States and other countries are virtually nonexistent." Casey (1989) noted that, during the 1980s, the availability of such data has become even worse. Casey demonstrated that for one worker population, farm equipment operators, existing data bases provide an extremely inaccurate model of the user group. During Phase 1, we obtained relevant measures of a large number of apparel manufacturing operators to compare with the few existing anthropometric data bases and also to provide designers an additional resource.

A second task was to identify problems related to workplace and job design in typical conventional apparel manufacturing operations, including those in transition to an advanced technology environment. These problems were identified through a combination of employee interviews and direct observation and measurement. Employee interviews were used to identify symptoms of workplace difficulties as well as the operators' perceptions of these difficulties and potential methods of improvement. Direct observation and measurement through the use of videotaping and physical measurement of relevant environmental characteristics were used to allow us to document and verify the nature and magnitude of the recognized (or as yet unrecognized) problems.

During Phase 2 of the program, we will test interventions that address some of the difficulties we have identified. During Phase 3, research will move into the high-technology manufacturing environment to address potential human factors problems. During Phase 4, we will produce a set of training materials to allow supervisors and middle and upper management to understand and address human factors issues in their workplaces.

2. METHODS

Site visits were conducted at three plants that manufacture trousers and are located in the Southeast. These plants were selected to provide a range of company sizes and degrees of automation that is typical of the industry. The numbers of workers employed by the three plants ranged from 50 to 600. Two of the three produce only military uniform trousers while the third produces a range of dress and casual trousers.

Employees in the jobs selected for video analysis were given the first opportunity to volunteer for interview and measurement sessions. Participation was then opened to all other employees. Interview and measurement sessions were held before work, after work, and during the lunch break and required approximately 30 minutes of each participant's time. Participants were paid for their time.

A total of 132 operators (123 female and 9 male) were interviewed and measured during the research. Interview data from two female operators was deleted because of language difficulties and job type. However, both subjects' measures are included in the anthropometric data base. The male data was not analyzed because of the small subject population. The "typical" female who participated in this study was forty years old with 103 months experience. Significantly, sixty-four percent of the female population was at least forty years old.

2.1 ANTHROPOMETRIC MEASURES

Anthropometric measures were taken on all interview participants. Subjects were measured in each of ten dimensions related to workstation and operator interface. The dimensions were selected for the following applications: cross-referencing (stature), work surface and display height (eye height, shoulder height, elbow height, and seated height), reach distances (arm length), seating characteristics (seated height, thigh clearance and popliteal height), and tool design (hand length and hand breadth).

Due to time and logistics constraints, the measuring apparatus utilized was portable and consisted of a GPM Model 101 anthropometer with baseplate and GPM Model 106 spreading caliper both graduated to whole millimeters. All measures were taken with shoes removed. Subjects were measured in their own clothing. Clothing was typically of a lightweight, summer type (e.g., shorts, t-shirts, cotton skirts, etc.). For standing measures subjects stood erect, facing forward. For seated measures, subjects sat erect on a flat surface. For shoulder height, elbow height, arm length, thigh clearance, popliteal height, hand breadth, and hand length, the subjects were measured consistently on the right hand side.

Measures were defined as follows:

1) Stature - Vertical distance from the floor to the crown of the head, measured with the subject standing. Subject was asked to report when the bar was felt on the top of head (as opposed to touching the hair) to confirm contact.
2) Eye height - Vertical distance from the floor to the inner canthus (corner) of the eye, measured with the subject standing.
3) Shoulder height - Vertical distance from the floor to the acromion, measured with the subject standing.

4) Elbow height - Vertical distance from the floor to the radiale (upper end of the radius), measured with the subject standing.

5) Arm length (Upper limb length) - Distance from the acromion to the fingertip with the arm fully extended parallel to the floor.

6) Seated height - Vertical distance from the sitting surface to the crown of the head. Subject was asked to sit up straight and, as with stature, report bar contact with the top of the head.

7) Thigh clearance - Vertical distance from the sitting surface to the top of the thigh tissue at its thickest point, typically (though not in all cases) where it met the torso.

8) Popliteal height - Vertical distance from the heel to the popliteal crease behind the knee.

9) Hand length - The distance from the wrist landmark (crease) to the dactylion (tip of middle finger).

10) Hand breadth - The distance between the second and fifth metacarpal-phalangeal joints.

2.2 INTERVIEW

Detailed interviews were conducted with all participants using a structured interview (form included in Appendix B). The participants (interviewees) were assured that their responses would be held confidential, and their names were not placed anywhere on the interview forms. To the extent possible, interviews were held in closed offices or in areas isolated from other employees to encourage candor in the responses. The interviews covered:

1) Demographic information
2) Work related injuries or musculoskeletal discomfort
3) Characteristics of the work environment
4) Characteristics of the workstation, chair, and job
5) Training
6) Work schedule
7) Other factors that might affect safety or productivity

During interview sessions, as many as three interviews might be occurring simultaneously in order to complete the large number of required interviews in the limited available time. To promote uniformity among the interviewers, most of the interview consisted of YES/NO, multiple choice, or short answer questions. The final two questions, however, were open-ended and the interviewer attempted to draw out more detailed information on previous interesting responses or suggestions on how the jobs might be improved.

Responses to interview questions were manually entered into a computer file for statistical analyses.

2.3 WORKSTATION MEASURES

Thirty individuals representing the fourteen jobs listed below were selected for video analysis. These jobs were "targeted" since they satisfied one or more of the following criteria based on discussions with supervisors, managers, and engineers: (1) job is in high skill category based on

productivity and training measures; (2) job has a history of CTDs; (3) job has a high level of absenteeism and/or complaints.

BUTTON HOLE	FLY LINING
PATTERN STITCH	POCKET WELT
SIDE SEAM	TRIMMING
SIDE AND INSEAM	SEAT SEAM
LEFT FLY	RIGHT FLY
SET AND CORD POCKETS	FACE AND CLOSE POCKETS
SLIDE AND STOP	TACK FRONT POCKETS

Of the jobs above, only trimming had a *documented* case of carpal tunnel syndrome in the past two years. Trimming, pocket welt, and slide and stop were standing workplaces (N = 5). The remaining jobs were performed in the seated work posture (N = 25). Where possible, two employees with different levels of experience were videotaped at each of the target jobs. Front, side, and back views were taken and analyzed using a computer video registration and analysis (VIRA) method described by Keyserling (1986) and Melin (1987) in the scientific literature. Videotape was reviewed in slow motion and the duration of time spent in each of four hand postures (dorsiflexion, flexion, ulnar and radial deviation) was documented for every subject. A posture change was noted when the hand movement resulted in at least a 15 degree departure from the neutral. Pinching (lateral and pulp pinches) and flat hand presses were also documented using this method. The number of posture changes was documented for each posture category as well. Back and neck angles were measured with the use of a protractor.

At each workstation selected for videotaping, measures of critical workstation dimensions were taken. Measures were taken both to support later video analysis and to provide a comparative dimensional baseline for use with anthropometric data in workstation evaluation. A metal tape measure was utilized for all linear measures. Basic dimensions selected included:

Work surface height, length, and width

Length and width of operator's work envelope (estimated)

Distance from the proximal edge of the work surface to the point of operation

Seat height, height including cushions or pillows (compressed), length, and width

Distance from the seat back to the proximal edge of the work surface

Reach distance (estimated) to raw material (e.g., piece on cart)

Reach distance (estimated) to finished material (finished good disposal)

Treadle location relative to work surface (plan view)

Treadle length, width and height

Cart or clamp truck dimensions

Location of obstructions where noted

Those measures indicated as estimated were taken using the tape measure to estimate the dimension reported in order to prevent interference with production. Work envelope was defined as the total travel area of the operator's hands during the course of operation on a piece or garment. It did not include initial reaches to obtain the work piece or reaches to dispose of finished work. Reaches

to raw and finished materials were measured from the operator's proximal shoulder to the grasp at the point of acquisition or release.

The workstation physical assessment also included measures of the weight of the work piece handled, how many were handled at one time (e.g., if 6-7 pieces were lifted at a time from the supply cart or truck to the operator's lap), the force required to actuate needle movement, and the force required to bring the machine to full operation. Forces and weights were measured using a Chatillon DFG-100 Digital Force Gauge. Any operator comments on workstation attributes were also recorded.

2.4 ENVIRONMENTAL MEASURES

2.4.1 Noise

A general noise survey was conducted at each facility using a General Radio Model 1982 Sound Level Meter (GenRad). The sound level meter was calibrated with a General Radio 1562-A Sound Level Calibrator before and after each survey. A representative sample of plant noise levels was obtained for both ambient noise and noise close to the operators' ears. At locations where the GenRad indicated levels approaching 90 dBA for an instantaneous measure, a Quest Electronics Model Micro 15 Permissible Noise Dosimeter was utilized to further investigate exposures. An employee in each target location volunteered to wear the dosimeter for a full shift.

2.4.2 Illumination

Lighting measurements were taken with a Gossen-Panlux light meter that is both color and cosine corrected to approximate the sensitivity of the eye to different wavelengths. Illuminance readings were taken at most sewing room task locations in each plant. Measurements were obtained with the probe in the horizontal plane close to the workstation point of operation (POO). Generally, two measurements were taken at each workstation: one with and one without the use of supplementary or task lighting (if available). The illuminance values collected were then compared to those recommended by the Illumination Engineering Society of North America (IESNA, 1981) for men's clothing manufacture. The IESNA illuminance categories and target values are based on the average age of the workforce, demand for speed and accuracy, and the background reflectance.

2.4.3 Temperature

A general temperature and thermal comfort survey was conducted at each facility using a Reuter-Stokes Model RSS-211D "Wibget" Heat Stress Monitor. A representative sample of levels was obtained for both dry bulb and wet-bulb-globe temperatures (WBGT) in degrees Fahrenheit.

3. RESULTS

3.1 ANTHROPOMETRY

The anthropometric population for the study totaled 123 female subjects. The population averaged 40 years of age (standard deviation 14 years, range 16-74 years). The mean, standard deviation, and 5th and 95th percentile values for each dimension are reported in Tables 1-3. Additional comparison values are provided from Society of Automotive Engineers publication SAE J833 DEC83 entitled "USA Human Physical Dimensions," MIL-STD-1472C, and HEW National Center for Health Statistics 1960-1962 study.

The following factors should be taken into account when comparing the data:

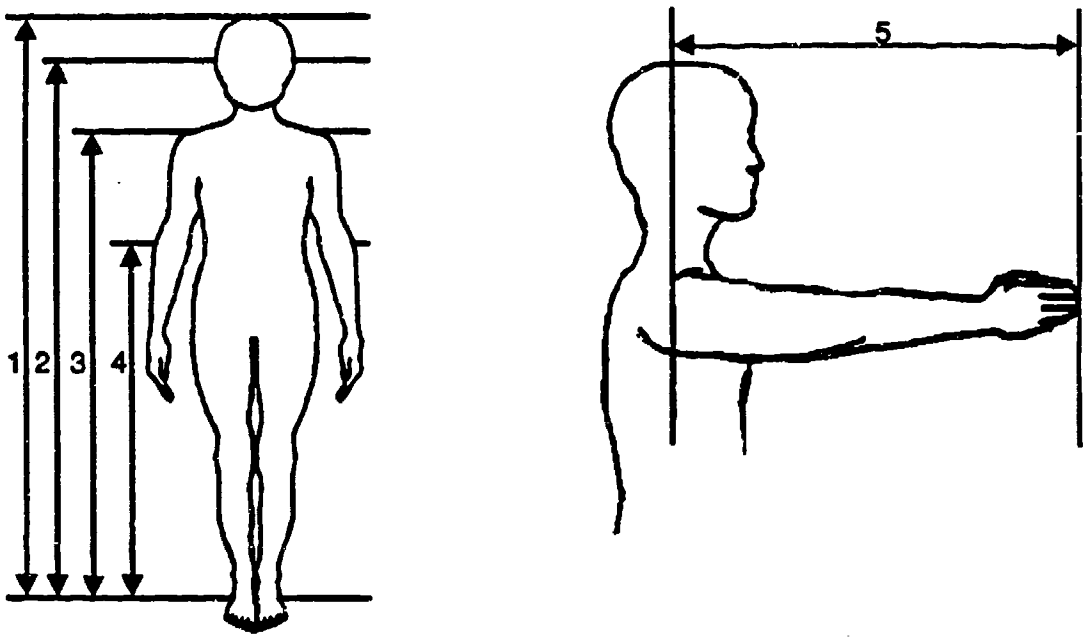
1) The HEW figures listed are taken from the NASA *Anthropometric Source Book*, Volume I—Anthropometry for Designers. It should be noted that the NASA reported figures represent only that part of the population between ages 25-40. The actual HEW study reports figures from ages 18-79. This somewhat limits comparison with the current study population. However, as the NASA document is considered a "good" reference for equipment design, the data is provided for comparison.
2) SAE J833 DEC83, presumably a civilian database, is actually a hybrid composed of both civilian and military data. The level of influence varies depending on the dimension selected.
3) The MIL-STD-1472C data is provided for comparison with female design criteria for military designs.

These notes point out the serious lack of current dimensional data for female civilians. As the comparative data provided is excerpted from some of the more commonly utilized design references, the level of potential design contamination due to data from military populations (which tend to have their own particular population characteristics) and limitation of the population age range (which influences distributions) is readily apparent. Designers should consider these factors when utilizing these sources.

3.2 MUSCULOSKELETAL DISORDERS

Based on the available 1988 and year-to-date 1989 OSHA 200 logs, the incidence of cumulative trauma disorders at Plants A and B (total of 4 cases) was approximately 167 cases per 10,000 employees. Plant C did not allow us to review their log information, but one case each of tendinitis, carpal tunnel syndrome, and bursitis was reported during the interview process. When employees at Plants B and C (N = 94) were asked if they experience joint numbness at night, 34 percent responded "yes". Approximately 90 percent of these individuals reported that the numbness involved the hands, wrists, and/or fingers. Since numbness of the hands, particularly at night, is a possible symptom of carpal tunnel syndrome, this finding suggests that the injury/illness records may not accurately reflect the true prevalence of CTS in the workplace. To substantiate this claim would require diagnostic measures and medical interpretation. Four back strains apparently due to bundle or fabric handling were also reported during this period with no detectable job trends.

Table 1. Selected Standing Body Dimensions of Female Apparel Manufacturing Workers



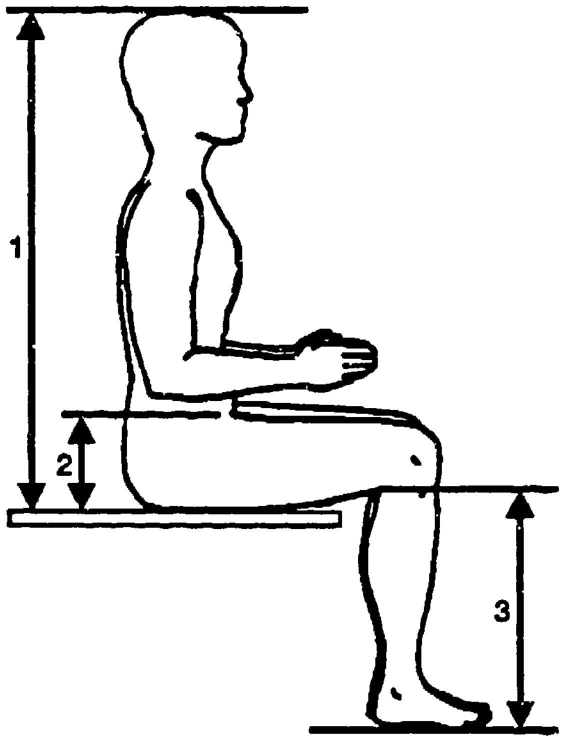
Dimension	Mean	SD	Percentile 5th	Percentile 95th	Source
(1) Stature (cm)	160.7	6.4	150.2	171.2	Current Study
	161.7	6.3	151.3	171.9	U.S. HEW Civilians [a]
	163.3	***	152.4	174.1	U.S. Army MIL-STD-1472C [b]
	160.0	***	150.0	170.4	SAE USA Physical Dimensions [c]
(2) Eye Height (cm)	150.6	6.2	140.5	160.7	Current Study
	***	***	***	***	U.S. HEW Civilians
	151.5	***	140.9	162.2	U.S. Army MIL-STC-1472C
	150.4	***	142.2	158.6	SAE USA Physical Dimensions
(3) Shoulder Height (cm)	133.3	5.9	123.7	143.0	Current Study
	***	***	***	***	U.S. HEW Civilians
	133.3	***	123.0	143.7	U.S. Army MIL-STD-1472C
	132.9	***	123.0	143.4	SAE USA Physical Dimensions
(4) Elbow Height (cm)	103.1	4.5	95.6	110.47	Current Study
	***	***	***	***	U.S. HEW Civilians
	102.8	***	94.9	110.7	U.S. Army MIL-STD-1472C
	***	***	***	***	SAE USA Physical Dimensions
(5) Arm Length (cm)	69.8	3.6	63.9	75.6	Current Study +

*** No comparison data available for this characteristic.

a, b, c See end of tables (p.) for references

+ No comparison data available

Table 2. Selected Seated Body Dimensions of Female Apparel Manufacturing Workers

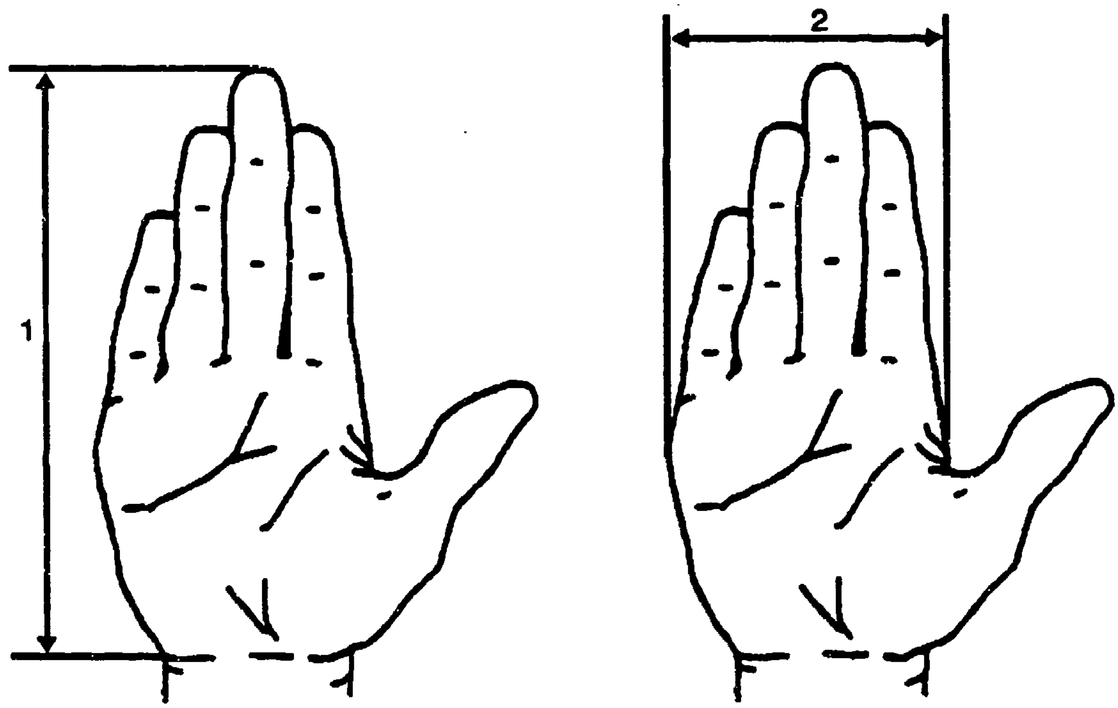


Dimension	Mean	SD	Percentile 5th	Percentile 95th	Source
(1) Seated Height (cm)	84.2	3.5	78.5	90.0	Current Study
	85.6	3.3	79.9	91.4	U.S. HEW Civilians [a]
	85.0	***	79.0	90.9	U.S. Army MIL-STD-1472C [b]
	84.8	***	78.5	90.7	SAE USA Physical Dimensions [c]
(2) Thigh Clearance (cm)	15.0	2.1	11.6	18.5	Current Study
	13.9	1.9	10.7	17.8	U.S. HEW Civilians
	14.0	***	10.4	17.5	U.S. Army MIL-STD-1472C
	13.7	***	10.4	17.5	SAE USA Physical Dimensions
(3) Popliteal Height (cm)	41.7	2.5	37.6	45.8	Current Study
	40.0	2.6	35.8	44.3	U.S. HEW Civilians
	41.8	***	38.0	45.7	U.S. Army MIL-STD-1472C
	39.9	***	35.6	44.5	SAE USA Physical Dimensions

*** No comparison data available for this characteristic.

[a, b, c] See end of tables (p.) for references

Table 3. Selected Hand Dimensions of Female Apparel Manufacturing Workers



Dimension	Mean	SD	Percentile 5th	Percentile 95th	Source
(1) Hand	17.5	.9	16.1	18.9	Current Study
Length	***	***	***	***	U.S. HEW Civilians [a]
(cm)	18.0	***	16.1	20.0	U.S.Army MIL-STD-1472C [b]
	17.9	***	16.1	20.0	SAE USA Physical Dimensions [c]
(2) Hand	7.8	.4	7.1	8.5	Current Study
Breadth	***	***	***	***	U.S. HEW Civilians
(cm)	7.7	***	6.9	8.5	U.S.Army MIL-STD-1472C
	7.4	***	6.9	8.4	SAE USA Physical Dimensions

*** No comparison data available for this characteristic.

[a] Stoudt, H.W., Damon, A., McFarland, P. and Roberts, J. (1965). Weight, height, and selected body dimensions of adults, United States, 1960-1962. *Vital and health statistics, series 11*, No. 8. Washington, D.C.: U.S. Dept. of Health, Education, and Welfare, as cited in:
Webb Associates. 1978. *Anthropometric Source Book, Volume I—Anthropometry for Designers.* (NASA Reference Publication 1024). Washington, D.C.: National Aeronautics and Space Administration. (NTIS No. N79-11734).

[b] Department of the Army. 1981. *Human Engineering Design Criteria for Military Systems*, MIL-STD-1472C. Natick, Mass.: U.S. Army Natick Laboratories.

[c] Society of Automotive Engineers. 1983. *USA human physical dimensions.* SAE J833 DEC83. Warrendale, Penn.: Author.

3.3 POSTURAL DISCOMFORT

Improper job design and badly designed workplaces can often create aches and pains in the muscles and joints of assembly workers. This can result from awkward working postures, excessive reaches to obtain or dispose of work, excessive manual manipulation of parts, excessive strength or muscular endurance requirements, or combinations of these factors. It is possible, therefore, to obtain clues about workplace and job design problems by exploring the patterns of musculoskeletal discomfort experienced by the operators while on or off-duty.

In addition, these data on musculoskeletal discomfort can provide information useful in establishing priorities for automation of particular sewing operations in the advanced technology sewing workplace. Chronic, work-related discomfort is one possible reason for attrition of highly skilled sewing operators as well as a potential cause of absenteeism and lowered productivity. If operations that are particularly stressful to the musculoskeletal system can be successfully automated, or if the conventional workplace can be modified to promote comfort, it will be easier to retain experienced, skilled workers and to maintain their productivity.

One goal of the Phase 1 effort was to document patterns of musculoskeletal injury or discomfort experienced by apparel manufacturing operators and to begin to correlate these discomfort patterns with the job and workplace elements that might be causing them. Using the procedures described in Section 2.2 (Methods), 121 female sewing operators rated the frequency with which they experienced muscular or joint soreness that might be related to their jobs in each of 16 areas of their bodies. Workers were asked to respond that they experience pain in a given area "never," "sometimes," "frequently," or "constantly."

The overall results are shown in Figure 1. Approximately half of all interviewed workers reported that they at least "sometimes" experience pain in their *upper back* (52%), *neck* (49%), and *right hand* (48%). One-third or fewer workers reported that they at least "sometimes" experience pain in their *right arm* (33%), *right leg* (26%), *right foot*, (26%), *right knee* (24%), *left arm* 24%), *left leg* (22%), *left foot* (20%), and *left knee* (17%).

On the bases of observation and of interviews with an experienced methods engineer, the sewing jobs were classified as requiring "low", "medium", or "high" amounts of manual manipulation of materials. High manipulation jobs identified were:

SIDE SEAM	SIDE AND INSEAM
TOPSTITCH	BLINDSTITCH BAND
TOPSTITCH LEFT FLY	ATTACH AND FINISH RIGHT FLY
SEAT SEAM	

Medium manipulation jobs were:

SET FRONT POCKETS	J-STITCH LEFT FLY
SERGE ZIPPERS AND FLIES	REPAIR TOPSTITCH WINGS
BIND BROADFALL	CROTCH PIECE
FACE AND CLOSE FRONT POCKETS	

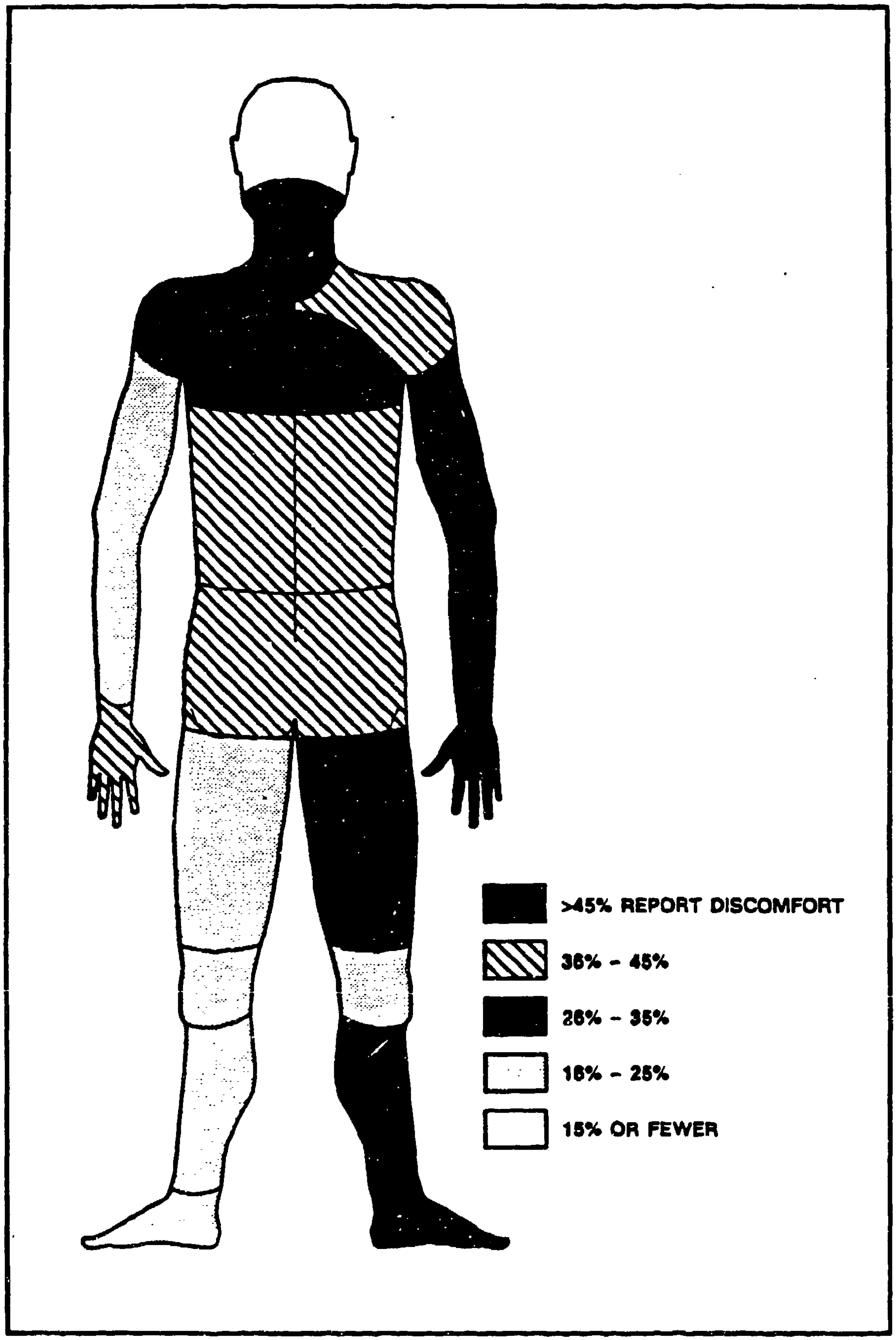


Figure 1. Percentage of Workers Reporting Musculoskeletal Discomfort by Body Area

Low manipulation jobs were:

TOP CORD BACK POCKETS	FACE BACK POCKETS
LABEL BACK POCKETS	MAKE LOOPS
TACK LOOPS	TRIM/INSPECT/SIZE TICKET
TAPE CROTCH	SPLIT BROADFALL
PATTERN STITCH	MARK BUTTON HOLES
EYELETS	FINISH BACK POCKET
ROCAP BANDS	PRESSING
BUTTON WRAP	HOOK AND EYE
SLIDE AND STOP	POCKET WELT
TURN POCKETS	SEW BACK DARTS

Figure 2 demonstrates the differences in discomfort frequencies between low manipulation and high manipulation jobs. Operators in high manipulation jobs reported substantially greater levels of musculoskeletal discomfort overall. Greatest discomfort levels were concentrated in the upper and middle back, neck, right shoulder, and hands. Seventy-three percent of the high manipulation operators reported pain in their right hands, the highest discomfort frequency identified by our analyses. Fifty percent of the low manipulation operators experienced upper back pain, roughly the same percentage as high manipulation operators (54%). In contrast to the general trend, the low manipulation workers reported almost double the frequency of lower back pain (39%) of the high manipulation workers (23%).

While the vast majority of jobs were performed while seated (97 of 121), a smaller number were performed standing (18 of 121) or both seated and standing (6 of 121). Some jobs (e.g., slide and stop and pocket welt) were done while standing at some locations and sitting at others. Figure 3 shows the differences in discomfort frequencies between the seated operators and the standing operators. It is apparent that overall discomfort is markedly less in the standing operations. As would be expected, standing workers reported a higher level of foot discomfort than did the seated workers. Complaints of pain in the back, neck and shoulders, however, were fewer, probably due to the more erect posture used by standing workers. Complaints of hand pain were fewer, probably because the standing jobs, on average, required less manipulation of materials.

An interesting trend was noted in analyses of discomfort frequency by operators of different chronological ages and levels of experience. Reports of musculoskeletal discomfort were most frequent among the relatively young workers (those between the ages of 26 and 35 years) and among those with one to three years of sewing experience. Substantially fewer reports were made by those over 55 years of age and those with over 25 years experience. This trend might be attributed to one or more of several factors. Some of the older workers appeared less willing to discuss their aches and pains, possibly fearing retribution by management. In other cases, older workers had been transferred to less physically demanding jobs. Finally, there is probably a significant amount of self-selection by which workers who are susceptible to musculoskeletal injuries leave this workforce and seek other jobs within the first years of work.

It was expected that we would find a substantial degree of similarity between the three interview sites in the discomfort experienced by the operators. This expectation was supported by the data. For each of the three sites, the 16 areas of the body were ranked according to the frequency with which work-related discomfort was reported at least "sometimes." Spearman Rank Correlation coefficients

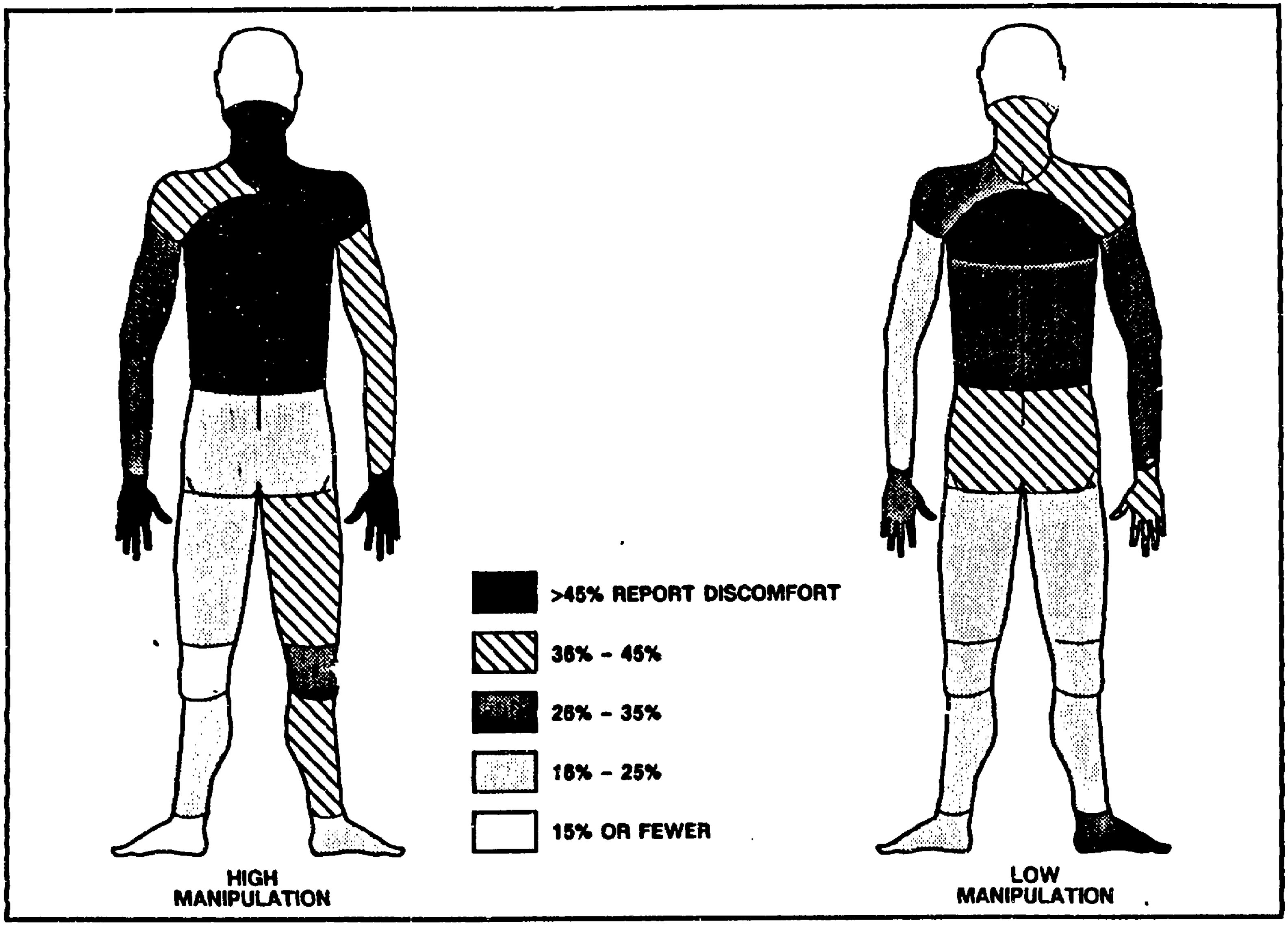


Figure 2. Percentage of Workers Reporting Musculoskeletal Discomfort in High Manipulation and Low Manipulation Jobs

mk.A8311.200.III-2

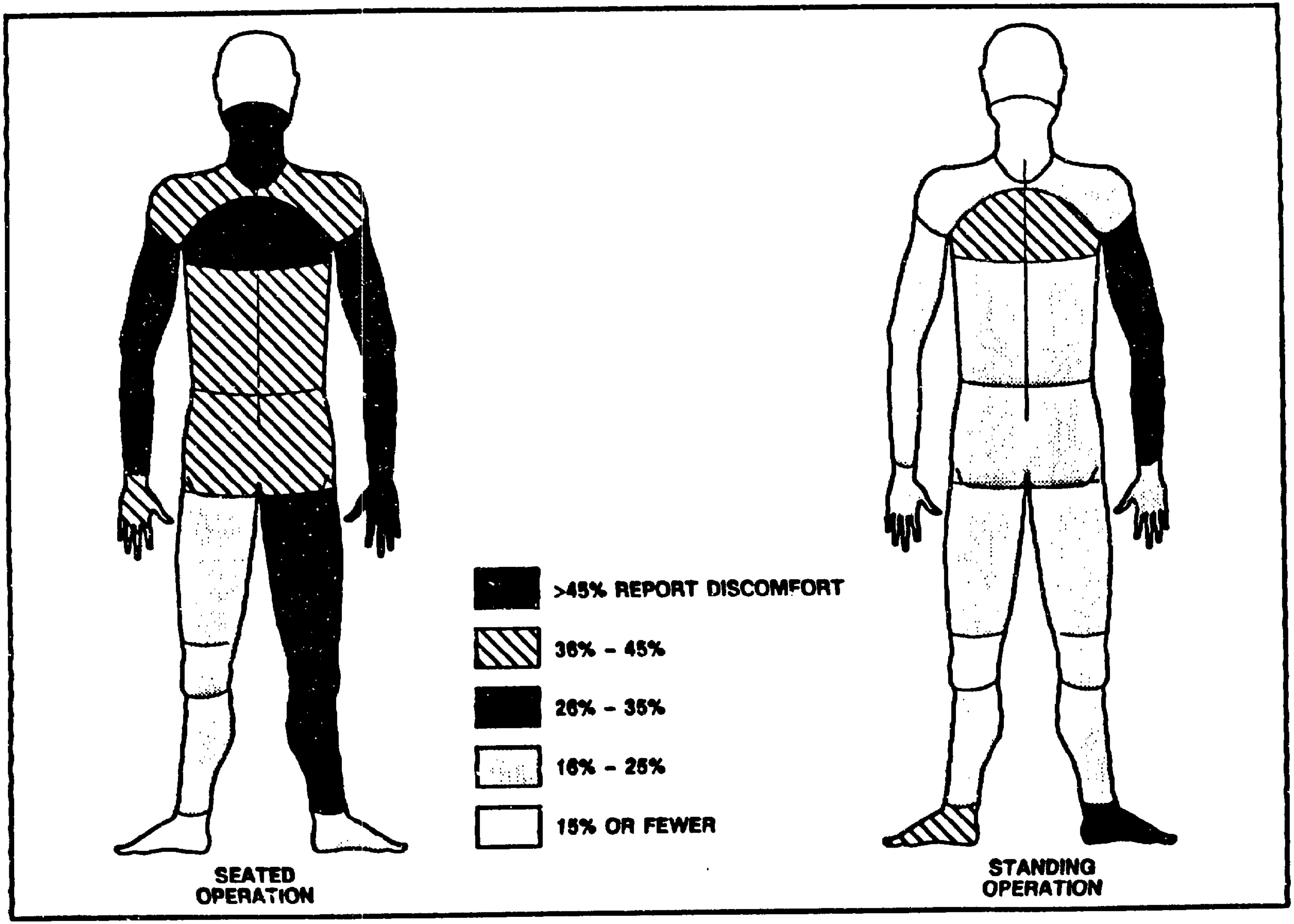


Figure 3. Percentage of Workers Reporting Musculoskeletal Discomfort in Seated and Standing Jobs

mk.A8311.200.III-3

were then calculated between each pairing of the three sites. Table 4 presents the results of these calculations.

TABLE 4. SPEARMAN RANK CORRELATION BETWEEN THREE INTERVIEW SITES OF BODY PART DISCOMFORT FREQUENCY

	SITE A	SITE B	SITE C
SITE A	1.00		
SITE B	.35	1.00	
SITE C	.54 *	[illegible]7 *	1.00

* Statistically significant beyond .05 level.

Probably the major difference between data from Site A and data from the other two sites is that there was little indication of hand and wrist discomfort at Site A. At Sites B and C, by contrast, hand pain was the most frequent physical complaint. At Site A, pain in the right shoulder was a major complaint while it was not at Sites B and C.

Site B had disproportionately larger amounts of foot discomfort, possibly because of a larger percentage of standing operations. There were also a larger number of complaints of right arm pain than at the other two sites.

It is important to be aware of the potential limitations on the validity of these body part discomfort data. Self-reports of work-related pain are subject to many biases. First, there are significant individual differences in what is perceived as pain and differences in what kinds of pain are attributed to work-related difficulties. Numerous workers reported discomfort in various parts of their bodies but attributed this to normal aging processes rather than to their jobs. Second, these reports depend on the memory of the operators being interviewed. Recent experiences with discomfort will likely be over-reported while experiences in the more distant past may be over-reported or under-reported. Finally, there may be a reluctance to report discomfort because of a fear of retribution by supervisors (even though workers were assured that interviews were confidential) or out of a sense of loyalty to the organization. Operators at one site seemed especially reluctant to report difficulties of any kind. While working conditions at this site were certainly no better than at the other two sites, both physiological and environmental complaints were substantially lower.

3.4. VIDEO ANALYSIS

3.4.1. Hands

The cycle time of the 14 jobs analyzed ranged from 10 to 109 seconds with most in the 20 to 40 second range. There were an average of 29.9 left and 25.6 right hand posture changes per cycle. Comparing individuals working at the same job with different experience levels shows that experienced employees work significantly faster than employees with less experience. This "working faster" also appears to be associated with greater hand activity per minute. Table 5 summarizes the video registration and analysis results. Duration is the percent of the cycle time spent in each posture category.

TABLE 5. VIRA RESULTS

POSTURE CATEGORY	DURATION Left Hand	DURATION Right Hand
Pinch (lateral and pulp)	50.1	54.9
Flat Press	25.7	19.5
Ulnar Deviation	29.5	29.8
Radial Deviation	7.2	5.5
Flexion	16.7	15.3
Extension	14.4	18.3

The results show small differences or symmetry between right and left hands for most of the posture categories. Further, there were no major differences concerning experience level and job manipulation category (see Section 3.3). Wrist ulnar deviation and pinching were the predominant wrist activities for most of the observed jobs. Right and left hand radial deviation was used less than 10 percent of the time by more than 70 percent of the subject population. Eleven employees used left hand pressing for 30 to 50 percent of the cycle time; only four employees used right hand pressing in the same duration category. The converse was true for the pinching activity. Eleven subjects pinched with the right hand for more than 60 percent of the time compared to five subjects who pinched with the left hand. Generally, the left hand was used for course manipulation involving a pinch grip and pressing to push or produce tension on the fabric. Fine manipulation was accomplished with the right hand, usually with a pinch grip.

3.4.2 Neck and Back

Overall, 40 percent (12) of the thirty subjects stooped forward (i.e., torso flexion) at least 20 degrees during the machine cycle. Sixty percent of the subjects tilted their heads more than 20 degrees throughout most of the machine cycle. This pattern did not change when looking only at the twenty-five subjects working at seated jobs. Sustained hunched-over work postures in excess of 20 degrees have been cited as a factor associated with muscle fatigue, pain and discomfort (Greenberg and Chaffin, 1976; and Grandjean,1988).

3.5 SEATED WORKSTATION CONSIDERATIONS

3.5.1 Workstation Design

Sixty percent of the seated workers indicated during the interview that they lean forward, usually to get closer to the work. This reported adaptation to visually demanding work is supported by the video analysis results (see Section 3.4.2). The preponderance of pain in the neck and upper back (Figures 1, 2, and 3) can be attributed, at least in part, to this hunched working posture. This hypothesis is supported by a comparison between seated and standing workstations (Figure 3). Workers in seated jobs reported substantially greater frequency of upper back pain (55%) and neck pain (54%) than did those in standing jobs who reported corresponding frequencies of 39% and 22% for the back and neck, respectively. Several workers stated that this posture is necessary to obtain maximum job production and wages in the piece-rate industry.

The tendency of operators to perform work in a bent or slumped posture indicated a potential conflict between workstation and operator dimension. Analysis indicated that the treadle typically is located too close to the proximal edge of the work surface (perhaps due to optimization for the 5th percentile or small operator). The conflict between leg room, comfortable leg posture for treadle operation, and the need for handling the piece at the point of operation (POO) results in one of two general postural adaptations. The most frequently observed was the case of nominal leg position (lower to upper leg angle roughly 110 degrees or greater) combined with 25-30 degrees of upper body deviation from the vertical. A second, rarely observed posture brought the operator closer to the POO at the expense of leg comfort (lower to upper leg angle 90 degrees or less). This second posture typically required foot extension (acute foot-lower leg angle) to maintain the machine in an idle mode and a greater degree of extension combined with twisting of the ankle to engage the treadle activated presser foot release.

Support for this observation came in two forms. In the operators measured, the average distance from the back of the chair (approximating proper normal back position) to the POO was only 3 cm less than the arm length of the 50th percentile operator. This indicated that dynamic activity at the POO would require a shortening of this distance (average reach required 84 cm, recommended reach 45 cm or less)(Kodak, 1983; Tichauer, 1978). The second analysis concerned treadle position. Average treadle position was roughly 15 cm from the proximal edge of the work surface.

A second factor limiting operator access to the workstation was the location of various obstructions under the work surface. These obstructions were typically drive motors, pneumatic equipment, power or pneumatic lines, and various machine guards. It is probable that these devices were located under the work surface to minimize interference with the work being performed on top of the surface, to create additional floor space, and even to improve equipment and personnel safety (relating to trip and fall hazards, burns, shock, etc.). However, the placement of these devices was not optimal for operator access in the majority of cases.

While typical minimum recommended leg/knee room averages around 46 cm (Diffrient, et. al., 1985; Kodak, 1983), the presence of these obstructions in some cases limited available space to less than 25 cm. Leg clearance also proved to be a problem in some cases where obstructions under the work surface reduced clearance room by 5-8 cm. This problem was somewhat insidious in that the clearance distance from the floor was still adequate in most cases, but with the placement of the foot on a treadle located around 8 cm off the floor, the potential for upper leg compression due to lack of clearance became evident.

The resultant postural adaptations that the obstructions and treadle placement necessitate contribute to fatigue. The most probable high impact areas would be the neck, upper back, shoulders, middle and lower back and arms. The greater distance from operator to POO also increases sight distance on a task which typically requires high acuity at the POO.

3.5.2 Chair Design

The chairs typically encountered in the sewing environment were generally too small in the seat pan, lacked any cushion for reducing compression and fatigue, lacked (though not in all cases) adjustable backrests, and were not properly adjusted in height. The chairs often had no provision for swiveling or other motion and no armrests for upper extremities support. In some cases, chair height was modified by the plant in conjunction with an increase in height in the workstation to accommodate the use of clamp trucks for garment bundle transport. These factors resulted in operator adaptations including the use of pillows or pads to improve comfort and seat support.

In contrast with recommended seat pan dimensions of 41 cm in length and 43 cm in width (Diffrient, et. al., 1985; Kodak, 1983) the average chair measured roughly 35 cm in length and 35 cm in width. In plants with chairs at normal heights, the height of the chair approximated the recommended height of around 40 cm off of the floor for the average female operator. However, the lack of adjustability would impact smaller and larger operators. The treadle height typically required a foot position at an additional 7-8 cm above the floor. At this height the larger operators' thighs would be largely unsupported and an uncomfortable acute torso to leg angle would be required to perform operations, exacerbating the conditions already noted under Section 3.5.1 (Workstation Design). At workstations adjusted for clamp trucks, seat height averaged 62 cm while treadle height averaged 24 cm. The stations adjusted for clamp trucks were not typically provided with a footrest for the operator to support the leg and reduce compression on the back of the thigh. For comparison, the 50th percentile female operator popliteal height was 41.7 cm.

Cushions were utilized by most operators (91 percent of the seated interviewees) with the possible benefits of improved height and increased pliancy and area of the load bearing surface (which would tend to reduce the effects of compression on both the buttocks and thighs as well as increase comfort). Some operators also used cushions on the chair back. The average cushion adjustment increased seat height by 3-6 cm when compressed.

3.5.3 Workstation Raw & Finished Material Access

Bundled materials were typically delivered on a clamp truck or horse-type cart. Location of the cart was adjustable by the operator in most cases. However, proximity to the operator's workspace was often limited by the amount of room required by the operator for processing the garment or piece and lack of physical space. This resulted in reaches to raw materials of roughly 48 cm on average with a discharge reach of 60 cm to finished goods. A recommended reach envelope for frequent lifting is 40 cm. Space problems frequently required that operators locate the truck or horse at an angle of 85 degrees or greater to the orientation of the torso. This required the operator to reach over and in some cases back at arm's length to obtain and discharge the materials. Operators were also observed twisting in the chair during lifts and attempts to move the cart or truck.

Note that operators using horses tended to pick up raw materials from one side of the body in a bunch of 4-8 pieces weighing 2-4 kg and discharge finished goods one piece at a time on the opposite side. Operators using clamp trucks handled single pieces (weighing an average of 0.5 kg) and acquired and disposed of them on the same side of the body.

3.5.4 Treadle Force

Treadle forces required to activate and sustain machine operation showed a great deal of variability. Only one plant's range of forces (though still highly variable) fell within the recommended ranges (Kodak, 1983; MIL-STD-1472C, 1981). The problem appears to be in maintenance. As the clutch device wears, the level of force required to activate the treadle changes. The result is a wide variation in forces required to operate between machines.

TABLE 6. COMPARISON OF MEASURED VERSUS RECOMMENDED FORCE RANGES FOR TREADLE ACTIVATION FOR ALL SITES

	Measured	Industrial (Kodak)	MIL-STD-1472C
Force range	5-98 N	15-90 N	45-90 N

3.6. ENVIRONMENTAL CONSIDERATIONS

3.6.1 Noise

Noise levels indicated the potential for exposure above U.S. OSHA regulations in some cases. Overall, the sites averaged roughly 82 dBA ambient with a mean of 83 dBA measured at the operators' ears. Dosimetry results identified serging as a consistent exposure area above the OSHA specified Action Level of 85 dBA for an eight hour shift and, in at least one case, above the permissible exposure limit of 90 dBA. The high noise levels in the serging areas are attributable to several factors:

1) The practice of grouping serging machines in a task cluster
2) The resultant maintained noise level due to several machines operating simultaneously during the majority of the shift so that the overall exposure rarely drops off
3) The combination of high frequency air noise and impact noise characteristic of serging machines

3.6.2 Illumination

Most sewing operations are visually demanding. Therefore, less than adequate lighting could cause workers to assume a hunched over posture to gain vision down into the work. The average general illuminance on the workstation (N=396) for all three locations was 78.4 footcandles (fc). Task illuminance, considered to be the combined illuminance of supplementary plus general lighting, was 168 fc. Whereas Plant A and B had similar values, they were substantially less than the Plant C facility averages. This appears to be due in part to the more effective use of fluorescent luminaires (i.e., lamps plus fixtures) at Plant C. In all three cases, however, most workstations provided less than 60 percent of the IESNA recommended value of 300 footcandles for performance of visual tasks of low contrast and very small size over a prolonged period. For working on white material with a high reflectance the recommended value is 200 fc. Most workstations provided less than 90 percent of this value. Sewing machine operators often do not use the available task lamps (i.e., supplementary lighting) or position them so they are less effective. Furthermore, in Plants A and B many fixtures were poorly maintained. Overall, 36 percent of the employees interviewed considered lighting to be a problem. Age and experience might be factors as 53 percent of workers in the 36 to 45 year age category and 53 percent of workers with 5 to 10 years experience reported lighting as a problem at least sometimes (i.e., at least a 2 rating on a 1 to 4 scale).

3.6.3 Temperature

Overall, the temperature levels in the sewing work environment reflected a nominal level of thermal comfort with with little fluctuation in temperature. Average temperatures ranged between 73-74 degrees F with an average WBGT ranging 65.7-67.6 degrees F. The mean dry bulb temperature varied less than 1 degree and WBGT index varied by less 2 degrees between plants. Distributions within plants were also fairly narrow with low standard deviation (e.g., 0.2 typical). These readings were obtained in plants which were climate controlled with air conditioning systems during the summer months. With the exception of non-air conditioned spaces and some types of pressing operations, thermal levels measured fell within the comfort range (roughly 68-78 degrees F). Even so, 87 percent of the interview population reported a problem with temperature at least some of the time.

3.7 TRAINING CONSIDERATIONS

Training of workers in the apparel manufacturing industry is an important consideration. Many of the jobs require the operators to learn complex psychomotor skills that can take many months to fully develop. In some jobs, as much as four months practice are needed to obtain the minimal skill level required to meet the standard production rates. Yet, apparel manufacturing in the Southeast is a high-turnover industry due, in great part, to the demand for inexpensive labor by other industries. Expensive training investments can be lost when new workers leave before or soon after their rates approach profitability.

Increases in production and productivity could be achieved if improved training methods reduced the time required for the development of the required sewing skills. Yet, at the sites studied in this phase, training was inconsistent and did not use methods found to be effective in other industries.

Initial training of sewing operators was performed as on-the-job training in all three of the plants we examined. One plant had a specialized training department responsible for initial and continuing training; the other two plants provided training by the floor supervisor. Training periods varied from a few days to as much as four months. None of the plants provided formal specialized training for their supervisors and trainers in effective methods for providing training and performance feedback to new workers or those transferring to a new job.

The 121 female sewing operators interviewed during the site visits were questioned about the training they received at the sites under study. Most reported that training consisted of a brief demonstration of the proper way to perform their assigned job with occasional follow-up suggestions at later times. Only 17% reported that they were shown or provided with any kind of charts, pictures, or written descriptions of how to perform their jobs.

The use of videotapes is gaining acceptance in many industries as a way to train psychomotor skills. Two of the three sites that were studied are making some use of videotapes but tapes are typically being made for engineering purposes rather than training.

Videotapes can be used to demonstrate exemplary performance. Star workers can be taped so that their work procedures and methods may be shown to new operators in that position to show how the job should be done and to prove that it is possible to make the required rates. In addition, tapes can be made of the person being trained in order to show deviations from the desired work methods. Videotapes provide the flexibility to allow slow-motion studies of methods and they can be replayed, in full or in part, as often as desired.

Of the operators interviewed, 13% reported that some use of videotape had been made during some portion of their training. Of the 16 operators who reported that videotape had been used, 31% reported that the tapes were used during their initial job training period while 69% reported that they were used during a change of jobs or to provide suggestions for improved work methods on their original job. Fifty-six percent of these workers reported that the slow motion capability was used to enable them to better see the sewing techniques being demonstrated. Sixty-three percent reported that they were allowed to study the tape for as long as they wanted while 37% would have liked more viewing time. Eighty-one percent reported that someone (a supervisor or engineer) was present to explain what they should learn from the tape while it was being shown.

Because of the hunched posture adopted by most of the operators, the interviewees were asked whether they had ever been instructed in the importance of correct posture while they are working. Only eight percent reported receiving such instruction. At one site, management stated that posture instruction is mandatory for all operators but, at this site, only four percent recalled receiving such

instruction. Obviously, if such instruction really is being presented, it is not having a major impact on the workforce.

Numerous jobs require the handling, lifting or moving of relatively heavy loads such as bundles of trousers. Yet, only ten percent of sewing operators reported that they had received training in the proper way to lift heavy articles. Seventeen percent of the operators reported that they had received instruction in other safety-related aspects of their jobs.

There was evidence, however, that improvements in employee training are being made, especially in the training of newly hired workers. Table 7 shows the percentage of workers at each of three experience levels who reported receiving training using visual aids and video tape, on posture, on lifting, and on other safety issues.

TABLE 7. PERCENTAGE OF OPERATORS REPORTING EACH KIND OF TRAINING

EXPERIENCE LEVEL (YEARS)	VISUAL AIDS	VIDEO TAPE	POSTURE TRAINING	LIFTING TRAINING	SAFETY TRAINING
LESS THAN 3	30%	10%	17%	13%	30%
3 - 10	15%	18%	7%	14%	14%
MORE THAN 10	12%	13%	5%	6%	11%

Based on these data, there appears to be a trend toward more complete training among the younger workers. The exception seems to be in the use of videotape in training. Recall, however, that operators reported only infrequent use of videotapes during their initial training. These data would suggest that the recent use of videotapes has concentrated largely on the more experienced workers rather than as a tool for initial training.

Performance feedback is an important element of psychomotor training. Because of the piece-rate nature of the industry, it is relatively simple to assign performance measures based on the number of pieces produced and the number rejected by inspectors. In one plant, a daily record of pieces produced is plotted against an ideal learning curve and posted above the workspace of each trainee. More direct and immediate means of feedback and performance remediation might be more effective.

In one plant, a computer controlled conveyor line provides a capability to display instantaneous readings of the current rate and earnings achieved by the operator on a screen at each workstation. Operators report that this capability is seldom used because it requires several keystrokes to obtain this display and the data are in a format that is not easily interpreted.

Recommendations for the improvement of training are included in Section 4.4 (Conclusions and Recommendations) of this report.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 ANTHROPOMETRY

When utilizing anthropometric data as an aid to workstation design, an appreciation of the following considerations can prove useful:

In examining the evidence, it is apparent that a design for an average person will not accommodate the significantly larger or smaller individual. To correct for this, designers usually will attempt to address the 90 percent of the population between the 5th and 95th percentiles. However, individuals will vary in their percentile score on each particular dimension. A person of 95th percentile height may have a 85th percentile arm length, etc. Additionally, every sub-population (e.g., all female operators in a plant) may vary from the larger population (e.g., HEW civilian females) as illustrated in Tables 1, 2, and 3. Considering these factors as well as the dynamic nature of the work performed at a sewing workstation, it becomes apparent that workstation design dimensions must incorporate adjustability to accommodate as much of the workforce as possible.

The data from this study may be used as a reference for designers attempting to develop equipment for the apparel manufacturing environment. The statistical significance of departures from the larger populations has not been assessed. However, the variations between the study data and existing sources of anthropometric design data indicate the need for proceeding with caution when utilizing these general design data sources.

4.2 WORKSTATION DESIGN

Among parts and assembly sewing operators, complaints of musculoskeletal discomfort focused on the upper extremities and torso. Video analysis of the target jobs revealed the presence of biomechanical or postural stressors that might account for this reported discomfort. The one common problem that clearly needs to be addressed is the lack of adequate chair and workstation adjustability.

All target jobs were hand intensive and the use of ulnar deviation, grasping with a pinch grip, and flat pressing was commonplace. This finding is important since forceful exertion (e.g., pinching), repetition, and non-neutral wrist postures (e.g., ulnar and radial deviation and flexion and extension) have been implicated as risk factors of cumulative trauma disorders. However, there was insufficient epidemiological data to support any relationship between posture, discomfort, and disease. With a large number of interviewees reporting night numbness of the hands, it is apparent that further research is needed to accurately determine the prevalence of CTDs in trouser manufacturing.

To eliminate the use of hand motions altogether will require automation. To reduce the amount of activity will require both workstation modifications and a careful examination of the piece rate system of payment that might encourage working at a fast pace. Wick and Drury (1986) have reported success in reducing the frequency of severe torso flexion, hand motion and ulnar deviation by modifying the workstation and providing adjustable chairs. Ostensibly, some of the high risk hand activity is nonessential and could be reduced through structured training in the importance of motion economy and biomechanics. But it is generally agreed that the training effect is at best temporary and will require further investigation.

It is well established that frequent and sustained forward flexion of the torso creates stress on the neck, back, and shoulders. The two factors identified that alone or together can cause the worker to assume this posture include poor lighting and a point of operation outside the normal viewing zone and reach envelope. The point of operation incompatibility is created by a rigid workstation and chair and/or the lack of adequate leg and table space. In Phase II we will measure the impact of using an easily adjustable, upholstered chair in combination with adequate lighting and posture training on back and neck posture and on emloyee comfort.

Frequent lateral reaches to acquire and dispose of fabric bundles can add to the loading of shoulder muscles, promoting muscle fatigue. This reaching activity in conjunction with chairs that lack a swivel capability can cause the employee to twist his/her upper torso, creating large stresses on the back. The use of swivel capable chairs, horses, clamp trucks, and other between station delivery systems should allow workers to transfer the garment or raw material without bending, twisting, or excessive reaching at or above shoulder height. Spring-loaded or self-leveling carts might prove useful. The design of the clamp trucks that require workstation height adjustments for their use needs to be re-evaluated by the manufacturer. The industry should seek a design that would be compatible with existing workstations and would allow trouser transfer without the garment legs dragging on the floor.

To promote comfort and work tolerance at standing workplaces, antistress mats could be used for more even weight distribution on the feet. Although sit-stand is preferred, it is not recommended for workstations that require a high degree of movement between task locations (e.g., zipper stop). PW back pockets was seen as both sit or stand. As with most work, the point of operation should be within two inches of elbow height (which can be estimated by taking sixty-three percent of stature).

Hand and power tools were rarely mentioned by interviewees as causing discomfort. This might be due in part to the absences of specific interview questions concerning their use. In any event, some employees were seen wearing band-aids which is indirect evidence that the frequent use of clippers and scissors might be a stressor. Scissors that are spring-loaded to assist the scissors opening process are commercially available, but their impact on comfort and performance is inconclusive (Tannen, Stetson, et. al., 1986). More consideration needs to be given to designing handles to allow workers to maintain a straight wrist while pressing, cutting, and trimming. Irons, trimmers, and cutters also need to be counterbalanced so the operator does not need to support the weight of the device. Vibration may be a potential problem with poorly maintained trimmers.

To keep the treadle activating force to a minimum, all machine treadles should be checked on a regular basis. Excessive force could result in leg and foot muscle fatigue.

4.3 ENVIRONMENTAL FACTORS

Inadequate illuminance can effect work performance and cause the operator to assume stressful postures to reduce the viewing distance from the work. Training in the use of available task lighting is needed and should focus on the need for adequate lighting and on proper lamp positioning. Maintenance of existing fixtures is also an important issue. When lamps begin to fail, they should be replaced immediately. For more effective overhead or general lighting, individual companies should consult with illumination engineers or consultants.

While the temperature ranges measured showed a level of temperature and humidity nominally within the comfort range, temperature ranked highest on the environmental problems section of the

interview. However, perception of thermal comfort has a high degree of variance between individuals. Influences on perception of temperature may include the time of day, diet, hormonal imbalances, season, type of clothing, etc. (Fanger, 1970).

With ambient noise levels averaging above 80 dBA, trouser manufacturing environments may need sound level assessment. This will of course depend on the nature and density of the noise source(s). Futher, it is important that equipment manufacturers apply the available and emerging noise suppression and abatement technologies in the equipment they design, manufacture, and distribute.

4.4 TRAINING

More effective training could increase productivity and improve safety. We would make recommendations in three basic areas: (1) training for the training staff, (2) increased use of audiovisual aids, and (3) performance feedback during training.

One of the most common mistakes made by organizations is the assumption that expert knowledge about a job is enough to make a person an effective teacher. In order to provide effective instruction, the trainer also needs to know something about the principles of learning and how to use them to best advantage. We would recommend that trainers, or supervisors who are called on to provide training, should be given at least a brief seminar on the use of learning principles in this specialized environment.

Audiovisual aids, including paper products such as job descriptions and diagrams and more advanced aids such as videotapes can produce a significant improvement in training effectiveness. Diagrams of correct techniques for operating equipment, posture, hand positions, and proper safety practices are learned more quickly and are remembered longer than simple verbal instructions, especially by the novice worker. Videotapes can be an even more effective training tool if they are effectively used to demonstrate ideal methods and performance. They are especially effective if a trainer is available to guide the training process, if features such as slow motion and multiple playbacks are used, and if the trainee has an opportunity to practice the skills during or immediately after presentation of the videotape training session.

It is important to provide immediate feedback to the trainee during practice of the job. Such feedback should have both performance and diagnostic components (e.g., your average cycle time was 47 seconds and you are making three significant extra hand motions that are slowing your time.) Because of the piece-rate nature of the industry, performance feedback is available on a daily basis. It could be available more often if the operator wanted to take the time to track production across smaller units of time, but this would be inconvenient and time consuming. As previously mentioned, computer controlled conveyor systems allow the achieved rate to be calculated and displayed, but this process is somewhat cumbersome and is seldom used. None of these approaches allows the kind of diagnostic feedback that is important to training in effective work methods. At a minimum, strict supervision by the trainer is important during the early periods of training and practice to ensure that proper methods are being learned. Videotaping of the trainee at selected times during the training period and careful review of the tapes with the trainee (using features such as slow motion) would provide better diagnostic feedback as well as allowing calculation of production speeds.

5.0 FUTURE CONSIDERATIONS

Some preliminary observations were made on an advanced technology computerized conveyor system seen at one plant location. The interview data showed that workers using this system (N=12) expressed a higher level of hand and leg discomfort than their counterparts that did not use the system. These preliminary results and observations will be carefully examined in Phase III. Initial observations are as follows:

1) The conveyor system may contribute to the ambient noise level.
2) The horizontal reach component was less at the advanced technology workstations. However, it might add a vertical component, which increases pronation in the acquisition of materials.
3) This conveyor system eliminates most cart or truck handling activities and allows the garment to approach the operator. Fewer pieces are handled at one time.
4) Flexible delivery (as opposed to standard rail delivery) may reduce some of the reach and posture problems noted in (2). The flexible system allows individual adjustment of delivery height and provides additional tolerance for pulling the garment to the workstation.

APPENDIX A

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APPENDIX B

INTERVIEW FORM

Date ____________________
Plant ____________________
Interviewer _______________

____

General
The following information will be used for describing the participants in terms of age, job, sex, and experience, and also in summarizing the results by those categories.

Job Title ____
Job is performed while: seated standing both. Age ___ Sex M F
How long employed at this plant ____________/on this job _____
Extent of previous employment in similar job (approx. years) ____

Major hobbies and sports activities (estimate average #hrs/week):

____

____

____

Medical Background
During the past twelve months, have you been treated by a doctor for any problem related to the muscles, tendons, or joints of your body? Examples of these problems are back strain, arthritis, tendonitis, herniated disc, and carpal tunnel syndrome. Yes No

If yes -- indicate diagnosis

____

____

Since you began working at this plant, have you ever worn a brace or support of any kind due to an injury or soreness? Yes No

(If yes -- indicate what and why) ____________________

____

Physical Discomfort

The following questions are about physical discomforts you may experience while working, or that you believe are work-related. Use the following scale to indicate how often you have experienced pain or stiffness in each body part within the past 6 months (or since starting to work here, if less than 6 months). (circle one)

	Never	Sometimes	Frequently	Constantly
Right hand/wrist	1	2	3	4
Left hand/wrist	1	2	3	4
Right arm (incl. elbow)	1	2	3	4
Left arm	1	2	3	4
Right shoulder	1	2	3	4
Left shoulder	1	2	3	4
Right foot/ankle	1	2	3	4
Left foot/ankle	1	2	3	4
Right knee	1	2	3	4
Left knee	1	2	3	4
Right leg	1	2	3	4
Left leg	1	2	3	4
Upper back	1	2	3	4
Middle back	1	2	3	4
Lower back	1	2	3	4
Neck	1	2	3	4

Do you ever have numbness in any of your joints at night? Yes No
(If Yes, elaborate below)

____

Do you ever have a problem with your feet or legs going to sleep while you are working? Yes No

List other physical discomforts you have experienced within the past 6 months that you believe are work related (for example, eyestrain, leg cramps, etc.):

____

Environmental Problems

The following questions are about problems that you may experience in your work environment. Use the same scale to indicate how often each condition creates problems in your job.

	Never	Sometimes	Frequently	Constantly
Temperature (hot/cold)	1	2	3	4
Drafts	1	2	3	4
Odors/fumes	1	2	3	4
Equipment noises	1	2	3	4

Other distracting noise	1	2	3	4
Amount of light	1	2	3	4
Glare from lights/windows	1	2	3	4

List any other environmental problem: ____________________________

Chair Design and Use

The following questions are about the chair you use while working. Answer Yes or No to each question. Skip these questions if your job is performed entirely while standing.

Does your chair have the following features:

adjustable seat height	Yes No
adjustable backrest	Yes No
swivel side to side	Yes No
tilt front to back	Yes No
armrests	Yes No
wheels or rollers	Yes No

(If seat height or backrest are adjustable, answer the following.)
Has anyone shown you how to adjust your chair? Yes No
Did anyone adjust the chair so it would be right for you? Yes No
Can you adjust the chair yourself? Yes No

Have you adjusted the height of your chair by putting it on planks, blocks, or similar items? Yes No

Have you used cushions in your chair to:
Raise your seating height? Yes No
Be more comfortable? Yes No

Do you use a footrest? Yes No

Do you have enough legroom under your work table so that your knees and legs are comfortable? Yes No

Workstation Design and Use

The following questions are about your workstation. Answer Yes or No to each question.

Does your job require you to:
- stretch either arm fully (or almost so) to reach things? Yes No
- bend, lean, or stoop to reach things? Yes No
- raise either arm above your shoulder? Yes No
- lifting a bundle (or other heavy item) with your arms? Yes No
- carry heavy loads from one place to another? Yes No
- push or pull a cart or horse? Yes No

Do you have enough space for:
- the stacks of pieces you work on? Yes No
- other work items (supplies, clippers or scissors, etc) Yes No
- personal items you have at work (purse, coffee cup, etc) Yes No

Do you ever have a problem with:
- work table height (too high or too low)? Yes No

- height/placement of your pedal, treadle, or knee switch? Yes No
- having to lean forward to see what you're working on? Yes No

List any other workstation problem: ______________________

Training

The following questions are about training you may have received at this plant. Remember that the questions are about training at this plant -- not other places you may have worked.

When you first started to work here, how long was your training period?

____

Have you received additional job training (such as for a different job) since then? (Indicate what type and how long)

____

____

In any of your job training at this plant, have you been given charts, work diagrams, or other written job descriptions to study and/or keep for yourself? Yes No (If yes -- indicate what)

____

Have you ever been shown a videotape of someone performing your job or a very similar job? Yes No

If yes --
- Was this done when you first trained for the job? Yes No
- Did you see it in slow motion? Yes No
- Were you allowed to study the tape as long as you wanted to? Yes No
- Did someone point out the major things you should be watching on the tape? Yes No

Have you ever been trained or instructed about the importance of correct posture in making you comfortable while working? Yes No

Have you ever been trained or instructed about the way to lift bundles or other heavy items? Yes No

Have you ever received safety training to show you how to operate your machine to reduce risk of accidents and injuries? Yes No

List any other special training you have received at this plant:

____

____

Work Schedule
These last questions are about how well your work schedule meets your needs. Answer Yes or No to say whether you think each thing would be better for you.

Earlier start time and quit time	Yes No
Later start time and quit time	Yes No
Longer lunch break	Yes No
Longer coffee breaks (indicate NA if not applicable)	Yes No
Flexible work hours (you get to choose what 8 hours you work between, say, 7 am and 7 pm)	Yes No

General Comments

Is there any part of your job that you think is a lot harder than other parts? Explain.

____

____

____

____

____

Now tell us more about any problems you mentioned in the earlier questions, and tell us anything else you believe would help make your job better for you.

____

____

____

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____

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____

____

APPENDIX C

SEWING OPERATOR EXAMPLES

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

PIECE GOODS ANALYSIS

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

FASHION INSTITUTE OF TECHNOLOGY

ANALYSIS OF APPAREL MACHINERY

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

SEWN LABELS

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

TEXTILE/CLOTHING TECHNOLOGY CORPORATION

ATTACHMENTS

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

NORTH CAROLINA STATE UNIVERSITY

FLEXIBLE MODULES

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

NORTH CAROLINA STATE UNIVERSITY

MARKET DEMAND FOR APPAREL AUTOMATION

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

INTEGRATED COST MEASUREMENT SYSTEM

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

NORTH CAROLINA STATE UNIVERSITY

APPAREL MANUFACTURING DATA BASE

MANUFACTURING TECHNOLOGY FOR APPAREL AUTOMATION CONTRACT DLA900-87-C-0509

NCSU Apparel Manufacturing Database

User groups:

GOVERNMENT/INSTITUTIONAL R&D

APPAREL MANUFACTURERS/CONTRACTORS

SUPPLIERS TO THE APPAREL AND RELATED INDUSTRIES

Applications currently underway:

- IDENTIFICATION OF GARMENT PART GROUPINGS SUITABLE FOR ASSEMBLY BY FLEXIBLE TECHNOLOGY CURRENTLY UNDER DEVELOPMENT BY NCSU-DLA CONTRACT
- DISCRETE EVENT SIMULATION DATA
- COST MODELING OF GARMENT STYLES
- COMPARISON OF RELATED GARMENT PARTS FOR CONSTRUCTION SIMILARITIES
- IDENTIFICATION OF OPERATIONS WHICH USE SIMILAR MACHINERY AND STITCHES
- BASIS FOR STANDARDIZATION OF TERMINOLOGY USED FOR OPERATIONS AND MACHINERY IN APPAREL MANUFACTURING

Public access available

Additional information:

Carrere, C. **"Consider Your Options: NCSU Apparel Manufacturing Database"**, *Apparel Manufacturer,* (1) 1, May 1989 pp.81-83.

CONSIDER YOUR OPTIONS
NCSU Apparel Manufacturing Database

by Carol Carrere

If you're planning to purchase new equipment or develop a new line of apparel, this information may be most helpful to you.

Current needs of the apparel manufacturing environment have been assessed by the North Carolina State University (NCSU), College of Textiles.

The development, manufacture and assembly of flexible, yet affordable equipment modules can be rationalized with the use of the new database available from NCSU.

The development work to build the database included the methods to handle the transfer of data, its verification and programming, organization, formatting and standardizing the terminology. The resulting, full-product database contains operation sequences, associated labor content and information about machinery used to perform the operations.

User-defined formats and the relational architecture of the database software make it easy to request, sort and report information. Unique features of this database have provided the foundation for research to be performed in several areas, including:

1. cost modeling of garment styles;
2. comparison of related garment parts for construction similarities;
3. identification of operations which use similar machinery and stitches;
4. identification of garment part groupings suitable for assembly by technology which is currently under development by NCSU and the Defense Logisitics Agency of the U.S. government; and
5. standardization of terminology used for operations and machinery in apparel manufacturing.

BUILDING THE DATABASE

In 1984, data was accumulated from a collection of cooperative apparel manufacturers. It was entered into the APS® by Leadtec® Apparel Production System. The funds were provided by (TC)².

This software provided an accepted format to enter the data; however, the tremendous scope of the sorting and synthesis for the job quickly challenged the fixed format of the software. As a result, when low-cost relational database software became available for use at the personal computer level, the APS® data was transferred to the new format. This was done in 1986, under the guidance of Leadtec®.

Data transfer and verification were completed during the summer of 1987. Those involved in the process included College of Textiles faculty, graduate and undergraduate students and the College of Computer Science.

Carol C. Carrere IS A RESEARCH ASSISTANT FOR THE APPAREL PROGRAM IN THE COLLEGE OF TEXTILES AT NORTH CAROLINA STATE UNIVERSITY.

SHAPING AND REFINEMENT

This effort has been assisted by the use of the relational database software, Knowledgeman®, from Micro Data Base Systems®. The transferred data has been categorized to show average, minimum and maximum number of operations (and the respective time values) associated with the assembly of each product type. A recombination of separate files, containing style, operation and machinery information, has been done, so that all associated information is easily located in one file.

Any reference to proprietary information, such as brand or company name, has been made "generic." The file has been purged of missing vowel/consonant combinations which showed up during initial data entry under the Leadtec® systems. This means that a single requested word is representative across the entire database. This purge process allows a current user to generate reports using specific "garment part/assembly action" combinations. (See the partial list, which is shown in Figure 1.)

Figure 1
Partial list of garment parts and assembly actions.

NCSU APPAREL MANUFACTURING DATABASE
(Partial Listing)

ACTIONS	# Citations	~~ACTIONS~~ PARTS	# Citations
SET	2281	POCKET	3053
TACK	1175	FLY	1168
SEW	1056	BAND	864
SERGE	1041	COLLAR	629
HEM	919	FLAP	467
STITCH	777	FACING	274
ATTACH	564	WELT	111
JOIN	370	EPAULET	35
RUN	32	COLLARSTAND	24
POSITION	14	PLACKET	16
OVERLOCK	11	LAPEL	14
OVEREDGE	9	UNDERCOLLAR	10
MATCH	8	BEARER	8
		COLLARBAND	5
		OUTLET	5
		COLLARLEAF	3
		COLLARSTAY	3
		PART	3

The term "Citations" refers to the actual number of times an action is mentioned within the data base.

"A company which is considering the purchase of new equipment, or the development of a new apparel line, can use the data to help them arrive at the correct decisions."

Report templates are generated to serve a variety of needs, which have been outlined by the researchers who are using the database. (See Figure 2 for a sample template.)

USING THE DATABASE

NCSU and the Defense Logistics Agency are using the database to assist them in the development of new technology. However, an apparel company which is planning to develop its own flexible technology might find the data helpful. Also, a company which is considering the purchase of new equipment, or the development of a new apparel

Figure 2
Example report format showing range of labor content in joining collar parts.

RUN: 02/03/89 13:46:28 — NCSU APPAREL MANUFACTURING DATABASE: PART/ACTION LISTING

OPERATIONS DESCRIPTION	BASE	SAH/100	RATE/100	MACHINE	CLASS	STYLE DESCRIPTION
Join Collar	C	1.16000	5.91600	ISU	301	Long Slv Shirt
Join Collar	C	1.21000	6.17100	S251-2	301	Short Slv Shirt
Join Collarstand/Interlining	D	1.28000	6.84800	S251-2	301	Long Slv Shirt
Join Collarleaf	D	1.32000	7.06200	S251-2	301	Long Slv Shirt - Khaki
Join Collar Assembly/Topstitch	D	2.59000	13.85650	S251-2	301	Long Slv Shirt
Join Collarstand/Collar	D	3.07000	16.42450	S251-2	301	Long Slv Shirt - Khaki
Join Collarstand & Collar Topstitch	D	3.14000	16.79900	S251-2	301	Women's Long Slv Shirt Khaki

line, can use the data to help them arrive at the correct decisions.

Guidelines may be analyzed, according to the needs of the user. For example, among other variables, these guidelines or parameters include:

- labor content values;
- stitch types; and,
- machinery used in assembly of related garment parts.

One method used to access the database allows the user to select from a list of "action words, combined with a list of garment "parts". These selections are set into appropriate command language, and yield results such as those shown in Figure 2. For the example shown, the word combinations *join* (assembly action) *collar, collarstand* and *collarband* (garment parts) were used.

Figure 2 results show the range of labor content values associated with performing the actions specified, machinery, stitch types used and a description of the product upon which the assembly action is required.

Further customized report formats allow statistical reporting, as well as mathematical operations which are performed on the data as selected from the database. For example, if desired, standard allowed hours per 100 units can be reported as standard allowed minutes per each. And, the minimum, maximum and average values of those times can be reported.

"Public access to the NCSU Apparel Database is now available. Hard copies of specifically requested information may be obtained on a Service Agreement through the NCSU College of Textiles."

CONSIDER THE OPTIONS

Public access to the NCSU Apparel Database is now available. Hard copies of specifically requested information may be obtained on a Service Agreement through the NCSU College of Textiles. Inquiries should be addressed to: Carol G. Carrere, NCSU College of Textiles, Box 8301, Raleigh, NC 27695-8301; Phone: 919-737-3442; FAX: 919-737-3926. **AM**

CIRCLE #28 ON READER SERVICE CARD

FEBRUARY 15, 1990

GEORGIA TECH

KNOWLEDGE BASED FRAMEWORK FOR TROUSER PROCUREMENT

DESIGN AND DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK FOR TROUSER PROCUREMENT

Research sponsored by:

U. S. Defense Logistics Agency

(DLA900-87-D-0018 CLIN 0007)

Principal Investigator: Dr. Sundaresan Jayaraman
Research Investigator: Dr. Howard Olson
Research Technician: Mr. Dale Stewart
Graduate Research Assistant: Mr. N. Sambasivan

Georgia Tech Project #: E-27-629

Georgia Institute of Technology
School of Textile Engineering
Atlanta, GA 30332

(404) 894-2490

July 1988 - January 1990

SJ-TR-PROC-FEB-15-90

A KNOWLEDGE-BASED

FRAMEWORK FOR TROUSER PROCUREMENT

AT DoD

Overview

* Need for the Research

* Benefits from this Research

* Research Objectives

* Tasks Accomplished

* Further Plans

* Acknowledgements

NEED FOR THE RESEARCH

* Department Of Defense procures $1.6 billion worth of apparel every year.

* Current procedure is to use sealed bids and award contracts to the lowest bidder.

* Details of current procurement procedures :

    * Invitation For Bids (IFB)

    * Request for Proposals (RFP)

    * Pre-Award Survey (PAS)

    * Certificate of Competency (CoC)

* Alternatives Available :

    1. Past Performance Considerations

    2. Develop a Reliable Method for Source Selection

1. Past Performance Considerations :

    * Entry Barrier for New Companies

    * Have Not Proven Effective

2. Developing a Predictor for Contractor Performance :

    * Knowledge-Based Framework

    * Can be extended to the whole apparel industry

    * Bidder most likely to deliver the greatest value is to be selected instead of the one who bids the lowest

    * Better Reliability and Explainability

    * Elimination of Human Bias

RESEARCH OBJECTIVE :

To assist in improving the Quality of the Decision made for Source Selection in Apparel Procurement

APPROACH

Develop a Knowledge-Based System which will help the Decision Maker to evaluate the contractors based on :

1. Production Capability

2. Quality Assurance

3. Quick Response Capability

4. Human Resources

6. Maintenance Procedures

7. Financial Capabilities

8. Customer Service

Tasks Accomplished

* Analysis of Current DoD Procurement Procedures

Questionnaire

Three Parts

Mailing: AMTC
AAMA Gov't Contracts Comm.
AAMA General Mailing

Part I: Contractor Performance

Quality, On-Time Delivery, Price, Quantity, History

Part II: Contractor Capability

Quality Capability
Production Capability

Part III: Processes

Quality Control
Sewing

Database of Sewing Machines

Technology Levels and Sewing Sequence

Machinery Database

	MANUFACTURER	MODEL	DESCRIPTION	TECH LEVEL
1	Adler	805-111[illegible]	automatic pocket set	4
2	Adler	804-3-ZE [illegible]-6	auto. pocket set	3
3	Atl. Attach	VC-110	beltloop auto cut & count	4
4	Atl. Attach	Walkertape	sederoll zipper feeding device	4
5	Atl. Attach.	1987	automatic waistband attach	4
6	Brother	B798-300ab	standard machine w/top feed	3
7	Brother	Bas-310	programmable tacker	5
8	Brother	BAS-311	auto. label sew	4
9	Brother	BAS-325	programmable tacker	5
10	Brother	BAS-700	auto. belt loop attach	4
11	Brother	BAS-750	automatic pocket set	4
12	Brother	CB3-B917	ticket tack/ buttonsew	2
13	Brother	DB2-748	programmable stitchcounter	4
14	Brother	DB2-B735-5	standard machine	1
15	Brother	DB2-B737-E100	programmable stitchcounter	4
16	Brother	DB2-B791-905	standard machine w/needle feed	3
17	Brother	DT6-B926-5A	off-the-arm design	1
18	Brother	Exedra 738	programmable stitchcounter	4
19	Brother	FD4-B271-OT2	belt loop sewer	2
20	Brother	LK3-B430	bartacker	3
21	Brother	LK3-B433/4/5/6	cam driven pattern tacker	3
22	Brother	LK3-B448/BA-15	auto. feed button sew	4
23	Brother	LK3-B484,5,6	cam driven pattern tacker	3
24	Brother	LS2-B837-300A	standard machine w/compound fe	3
25	Brother	LT2-B838	standard machine w/compound fe	1
26	Brother	LT2-B842-905	standard machine w/needle feed	3
27	Brother	LT2-B845-907	needle feed/split needle bar	3
28	Brother	LT-B872	standard machine w/needle feed	3
29	Brother	LT-B875	split needle bar	3
30	Brother	MA4-B551	standard machine	2
31	Brother	MA4-B661	standard machine	2
32	Brother	MA4-B694	standard machine	2
33	Durkopp	211	standard machine	3
34	Durkopp	212	needle-feed machine	3
35	Durkopp	271	standard machine	3
36	Durkopp	272	standard machine w/needle fee	3
37	Durkopp	274	standard machine w/compund fee	3
38	Durkopp	291	standard machine w/compund fee	3
39	Durkopp	294	needle feed/split needle bar	3
40	Durkopp	558	buttonhole	3
41	Durkopp	570	bartack	3
42	Durkopp	743	auto. sew darts	4
43	Durkopp	DAP 12-28-1	auto. cut and sew belt loops	4
44	Durkopp	271-140040	programmable stitchcounter	4
45	Durkopp	272-140040	programmable stitchcounter	4
46	Durkopp/Diana	563	ticket tack/ buttonsew	2
47	Pfaff	1442	standard machine	3
48	Pfaff	1446-706/07	standard machine w/top feed	3
49	Pfaff	3336	cam driven pattern tacker	3
50	Pfaff	3337	cam driven pattern tacker	3
51	Pfaff	3568	automatic pocket set	4
52	Pfaff	3819	automatic waistband attach	4
53	Pfaff	481/980	programmable stitch counter	4
54	Pfaff	483-980	programmable stitch counter	4
55	Pfaff	5489	standard machine w/differentia	3
56	Pfaff	561	standard machine w/needle feed	3

Machinery Database

RANKING FEATURE	STITCH	COST $	OPERATING SPEED (Stitches/min)	MAXIMUM SPEED (Stitches/min)
manufacturer engineered	301-1			
cam control	301-1			
automatic workaid	N/A			n/a
automatic workaid	N/A			n/a
manufacturer engineered	301-2			
electronic motor control	301-1	$3,270	2000	2000
multi-function programmable	301-1	$9,950	2000	2000
manufacturer engineered	301-1			2000
multi-function programmable	301-1	$16,288	2000	2000
manufacturer engineered	301-1	n/a		2000
manufacturer engineered	301-1	$48,500	3000	3500
undertrimmer	101-1	$2,314	1500	1500
programmable electronic motor	301-1			3500
	301-1	$1,040	5000	3500
programmable electronic motor	301-1	$2,863	5000	4000
electronic motor control	301-1	$3,427	3500	3500
	401-2/3	$3,314	3600	3600
programmable electronic motor	301-1	$3,730	5000	3500
folder	406-2	$2,907	6500	7000
cam control	301-1	$3,655	2300	2300
cam control	301-1			2000
automatic workaid	301-1			2000
cam control	301-1	$4,151	2000	2000
electronic motor control	301-1	$5,404	3000	3000
	301-2	$2,157	3000	3000
electronic motor control	301-2	$4,699	3000	3500
electronic motor control	301-2	$5,997	3000	3000
electronic motor control	301-2	$2,681	3000	3000
electronic motor control	301-2	$3,426	3000	3000
thread trimmer	515-2	$2,050	6000	6000
thread trimmer	515-2	$2,289	8000	8000
thread trimmer	515-2			5500
electronic motor control	301-1			4800
electronic motor control	301-1			5000
electronic motor control	301-1			5500
electronic motor control	301-1			5000
electronic motor control	301-1			5000
electronic motor control	301-1			4000
electronic motor control	301-2			4000
cam control	404-1			2000
cam control	301-1			2500
manufacturer engineered	401-1			
manufacturer engineered	301-1			
programmable electronic motor	301-1			5000
programmable electronic motor	301-1			5000
undertrimmer	101-1			1500
electronic motor control	301-2	$7,800	4000	4000
electronic motor control	301-2	$8,600	3600	3800
cam control	301-1	$5,700	1800	1800
cam control	301-1	$5,000	2000	2000
manufacturer engineered	301-1	$52,000	4100	2800
manufacturer engineered	301-2	$25,600	4000	4000
programmable electronic motor	301-1	$6,000	6000	6000
programmable electronic motor	301-1	$4,300	6000	6000
electronic motor control	401-1	$11,200	5500	4600
electronic motor control	301-1	$3,000	5000	5000

Machinery Database

EST. LIFE (Years)	**TYP. LIFE	**RELIABILITY	**MAINT. COSTS($)	SPACE	OPERATOR TRAIN TIME (hours)
				n/a	
				n/a	
				2'x5'	
8				2'x4'	4
8				2'x4'	4
8				2'x4'	
8				2'x4'	4
8				2'x3'	
8				4'x5'	16
8				2'x4'	3
8				2'x4'	
8				3'x4'	3
8				2'x4'	3
8				2'x4'	3
8				3'x3'	4
8				2'x4'	16
8				3'x4'	4
8				3'x4'	4
8				3'x4'	
8					
8				2'x4'	4
8				2'x4'	3
8				2'x4'	3
8				2'x4'	4
8				2'x4'	4
8				2'x4'	4
8				2'x4'	4
8				2'x4'	4
8				2'x4'	4
8				2'x4'	
				2'x4'	
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				2'x4'	
				2'x4'	
				2'x4'	
				2'x4'	
				2'x4'	
				3'x3'	
				3'x3'	
				2'x4'	
				2'x4'	
				2'x4'	
20				2'x4'	4
20				2'x4'	4
20				2'x4'	4
20				2'x4'	4
20				5'x7'	40
20				2'x5'	80
20				2'x4'	4
20				2'x4'	4
20				2'x4'	4
20				2'x4'	4

Machinery Database

MECHANIC TRAIN TIME (hours)	REQUIRED PARTS INV. ($)	DELIVERY (months)	USERS & PHONE	
				1
				2
				3
				4
				5
3	275	0.5		6
12	475	1		7
	275	0.5		8
12	475	1		9
	275	0.5		10
24	5000	3		11
6	275	0.5		12
	275	0.5		13
3	275	0.5		14
3	275	0.5		15
3	275	0.5		16
6	275	0.5		17
6	275	0.5		18
6	275	0.5		19
6	275	0.5		20
	275	0.5		21
	275	0.5		22
6	275	0.5		23
3	275	0.5		24
3	275	0.5		25
3	275	0.5		26
3	275	0.5		27
6	275	0.5		28
6	275	0.5		29
6	275	0.5		30
6	275	0.5		31
	275	0.5		32
				33
				34
				35
				36
				37
				38
				39
				40
				41
				42
				43
				44
				45
				46
32	$780	3		47
32	$860	0.5		48
32	$570	2		49
32	$500	3		50
80	$5,200	4		51
80	$2,560	4		52
32	$600	0.5		53
32	$430	0.5		54
32	$1,120	6		55
32	$300	0.5		56

Best-case operation sequence with Technology Levels

Operation	Technology Level
Make belt loops	4
Hem front pockets	3
Hem back pockets	3
Buttonhole back pocket	2
Serge and attach left fly to zipper	3
Cut out zipper gap	3
Attach zipper slider and bottom stop	3
Line and topstitch right fly	3
Attach right fly to zipper	2
Make back darts	4
Topstitch back darts	5
Attach back label	5
Attach back pockets	4
Sew seatseam	3
Attach front pockets	4
Attach and cord left fly	3
Topstitch left fly	4
Attach right fly and join fronts	3
Sew sideseam	2
Sew inseam	2
Attach waistband	4
Close waistband ends	5
Buttonhole band	2
Buttonsew back pocket and waistband	3

Attach belt loops	4
Tack Fly	2
Attach size label	2

Mid-case operation sequence with Technology Levels

Operation	Technology Level
Make belt loops	3
Hem pockets	3
Crease pockets	2
Buttonhole back pocket	2
Serge left fly	2
Attach left fly to zipper	3
Scoop cut zipper	3
Line right fly and topstitch	3
Serge right fly	2
Attach front pockets	3
Bartack front pockets	2
Attach flies	3
Cord left fly	3
Topstitch left fly	3
Join fronts and tape crotch	3
Attach slider and bottom stop	3
Sew darts	3
Topstitch darts	3
Attach back label	3
Attach back pockets	3
Bartack back pockets	2
Sew seatseam	2
Sew sideseam	2
Sew inseam	2
Attach waistband	3

Finish waistband ends	3
Buttonhole waistband	2
Buttonsew waistband and back pocket	2
Attach belt loops and bartack fly	3
Attach size ticket	2

Worst-case operation sequence with Technology Levels
Taken from MIL-T-87062A

Operation	Technology Level
Make darts and attach label	1
Hem pockets	2
Make loops	2
Crease pockets	2
Attach pockets	1
Serge left fly	1
Attach Zipper	2
Scoop cut zipper	2
Line right fly	1
Serge right fly	1
Join flies (8.e. & f.)	1
Attach flies	1
Slide & stop	2
Join crotch & seatseam	2
Side & inseam	2
Attach band & close ends	1
Attach loops	1
Tack pockets & fly	1
Buttonhole	2
Buttonsew	1
Tack ticket	1

Performance criteria

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	MEAN	STD	
Meet quantity rqmts.	3	3	2	5	2	1	4	2	3	3	3	1	5	3	3	5	5	3	3.11	1.24	4
Meet quality rqmts.	1	4	1	2	3	1	1	1	1	2	1	1	1	1	1	1	1	1	1.39	0.83	1
On time delivery	2	2	2	1	2	2	2	1	2	4	2	1	3	2	2	2	2	2	2.00	0.67	2
Price	4	1	3	3	4	3	3	2	2	1	4	2	2	4	1	3	3	3	2.67	1.00	3
History of firm	5	5	4	6	1	2	5	3	4	0	5	1	4	5		6	4	4	3.76	1.73	5
Other				4	5						6	1				4	6		4.33	1.70	6

TOLERANCES	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	MEAN	STD
QUANTITY	2	2	2	0	2				10		10		2	0	5	3		2	3.33	3.22
QUALITY	1	4		3	1	3		4			3		2	1	2	1		1	2.04	1.23

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	MEAN	STD
TIME	5	0	15	5	15				0		10		14	0	3	3		1	5.92	5.74
PRICE	10	0									3		1					2	3.10	3.56
OTHERS																			ERR	ERR

Ranking of capabilities

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	MEAN	STD
Production capabilities	3	1	4	1	1	1	2	2	2	1	2	5	1	5	1	1	2	3	2.11	1.33
Human res. (Operators)	5	4	5	3	2	2	7	2	6	9	4	5	3	6	4	5	4	2	4.33	1.86
Quality assurance	6	3	2	2	5	1	1	1	1	2	1	5	2	1	2	2	1	1	2.17	1.54
Maintenance	8	7	7	0	8	5	4	6	4	10	9	5	7	7	10	6	8	6	6.50	2.34
Quick response capability	4	0	8	0	7	8	0	3	3	6	7	5	0	2	6	8	5	3	4.17	2.85
Financial resources	7	2	1	5	6	3	8	5	5	3	3	5	4	8	3	10	3	5	4.78	2.27
Warehousing & distribution	9	0	9	0	10	7	0	0	9	7	8	4	8	0	5	11	10	6	5.72	3.93
Customer service	10	0	10	0	9	4	5	4	0	4	6	5	5	0	7	3	9	4	4.72	3.28
Management system	1	6	3	4	4	6	3	7	0	5	5	5	6	4	8	4	7	4	4.56	1.98
Materials handling system	11	5	6	0	11	9	6	0	0	8	10	4		3	9	9	6	7	6.12	3.60
Other	2				3	1										7			3.25	2.28

RANK EFFECT

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	MEAN	STD
Production capabilities	4	5	4	5	5	5	4	5	5	5	4	5	5	5	5	5	4	3	4.61	0.59
Human res. (Operators)	3	3	4	5	5	4	1	5	4	4	3	5	5	3	4	4	4	4	3.89	0.99
Quality assurance	3	5	5	5	4	5	5	5	5	4	5	5	5	5	5	5	5	5	4.78	0.53
Maintenance	2	3	3		3	3	2	2	4	3	3	5	3	2	3	4	3	2	2.94	0.80
Quick response capability	4		3		3	1	1	4	4	4	4	5	2	5	4	3	4	3	3.38	1.17
Financial resources	3	4	4	3	3	4	2	2	4	3	5	5	4	3	5	3	3		3.53	0.92
Warehousing & distribution	2		3		2	2	1		2	3	3	5	2		4	2	3	2	2.57	0.98
Customer service	1		2		2	3	3	4	1	4	2	5	4		4	4	4	3	3.07	1.18
Management system	5	3	4	4	4	2	3	2	1	3	4	5	4	3	3	5	3	2	3.33	1.11
Materials handling system	1	4	3		2	1	1		1	2	1	4		4	3	3	3	2	2.33	1.14
Other	5				4	5					4					4			4.40	0.49

Ranking of processes

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	MEAN	STD
Raw materials	6	4	1	5	4	3	0	4	4	1	4	1	3	0	2	6	4	2	3.00	1.83
(fabric, thread, etc.)																			0.00	0.00
Cutting	2	3	3	2	2	3	3	2	3	0	2	1	4	0	3	4	3	1	2.28	1.15
(marker, packing)																			0.00	0.00
Sewing	3	2	3	1	1	2	2	1	2	0	3	1	1	2	1	2	1	2	1.67	0.82
(operators, machines)																			0.00	0.00
Quality control	1	1	2	3	3	1	1	1	1	2	1	1	2	1	4	1	2	3	1.72	0.93
Packaging	4	5	4	4	6	4	0	3	6	3	5	2	5	0	5	5	5	3	3.83	1.71
Shipping	5	6	4	6	5	5	0	0	5	4	6	2	0	0	6	7	5	3	3.83	2.34
Other											7	0				5			4.00	2.94

EXPERT KNOWLEDGE THROUGH QUESTIONNAIRES

* **First Set of Questionnaires :**

    * **Statistical Analysis yielded some important guidelines for assigning weights**

    * **Satisfying *Quality Requirements* emerged as the most important attribute for evaluating the contractor**

    * **No good indication was available about attributes as well as their weights for lower level objects**

    * **Human Expert Decision process did not seem to take care of objects deeper in the semantic network**

    * **Human Experts differed a lot from each other in all levels except in level 1**

* **Second Set of Questionnaires**

  * **AAMA Government Contracts Committee Meeting**

  * **AAMA General Mailing**

Knowledge Representation

* Object Networks
* Two-Step Evaluation Process

    QC_Capability

    Production_Capability

    Financial_Capability

Price

KNOWLEDGE REPRESENTATION

* Semantic Network of Objects

* Objects are the Criteria for evaluation (Contractor is an object)

* Hierarchy of Objects (Levels)

* Object - Attribute Value Representation

* Attribute Value of Object in one level depends on

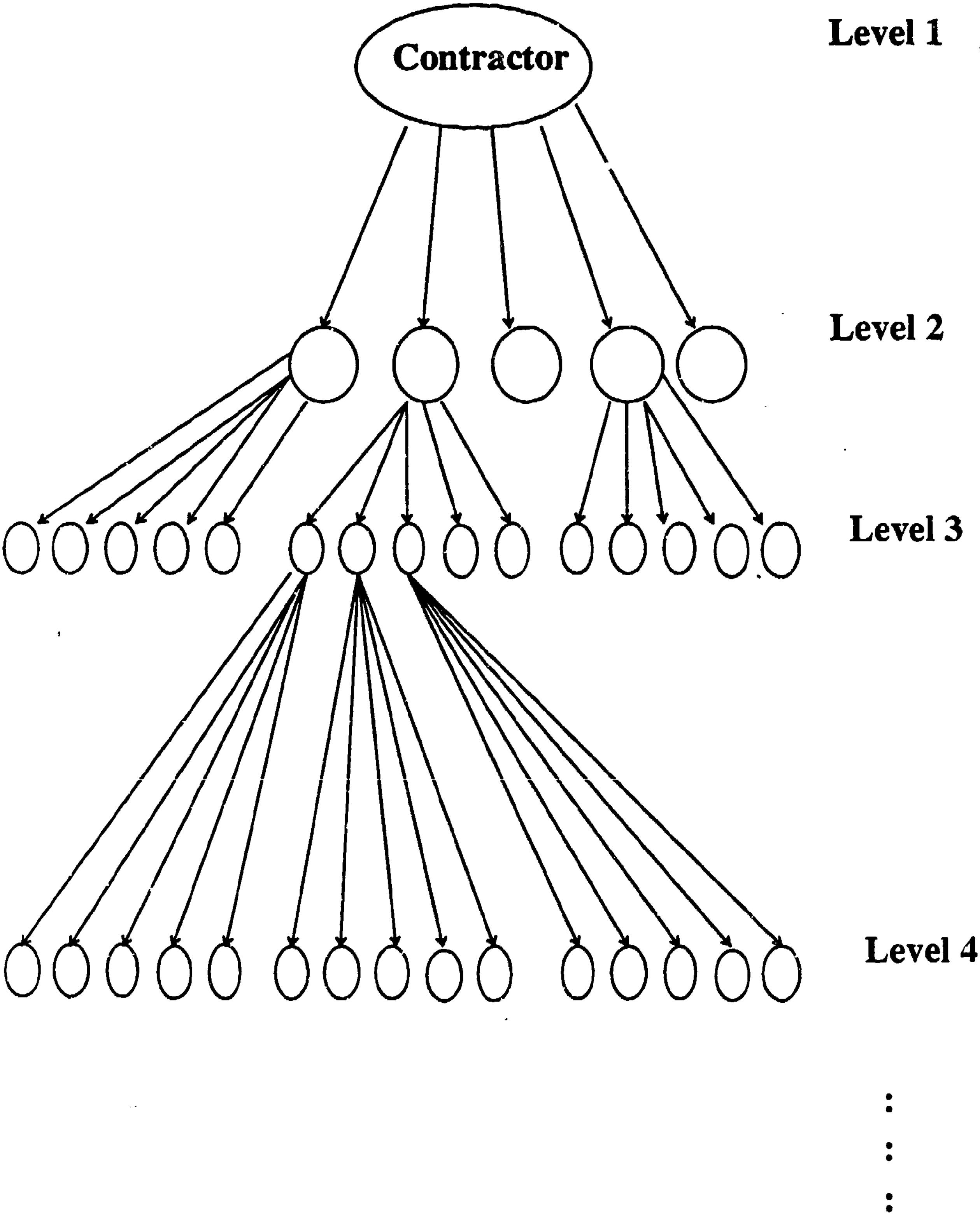
  1. Attribute Values of Objects in the next level and connected to the Object under consideration in the Semantic Network.

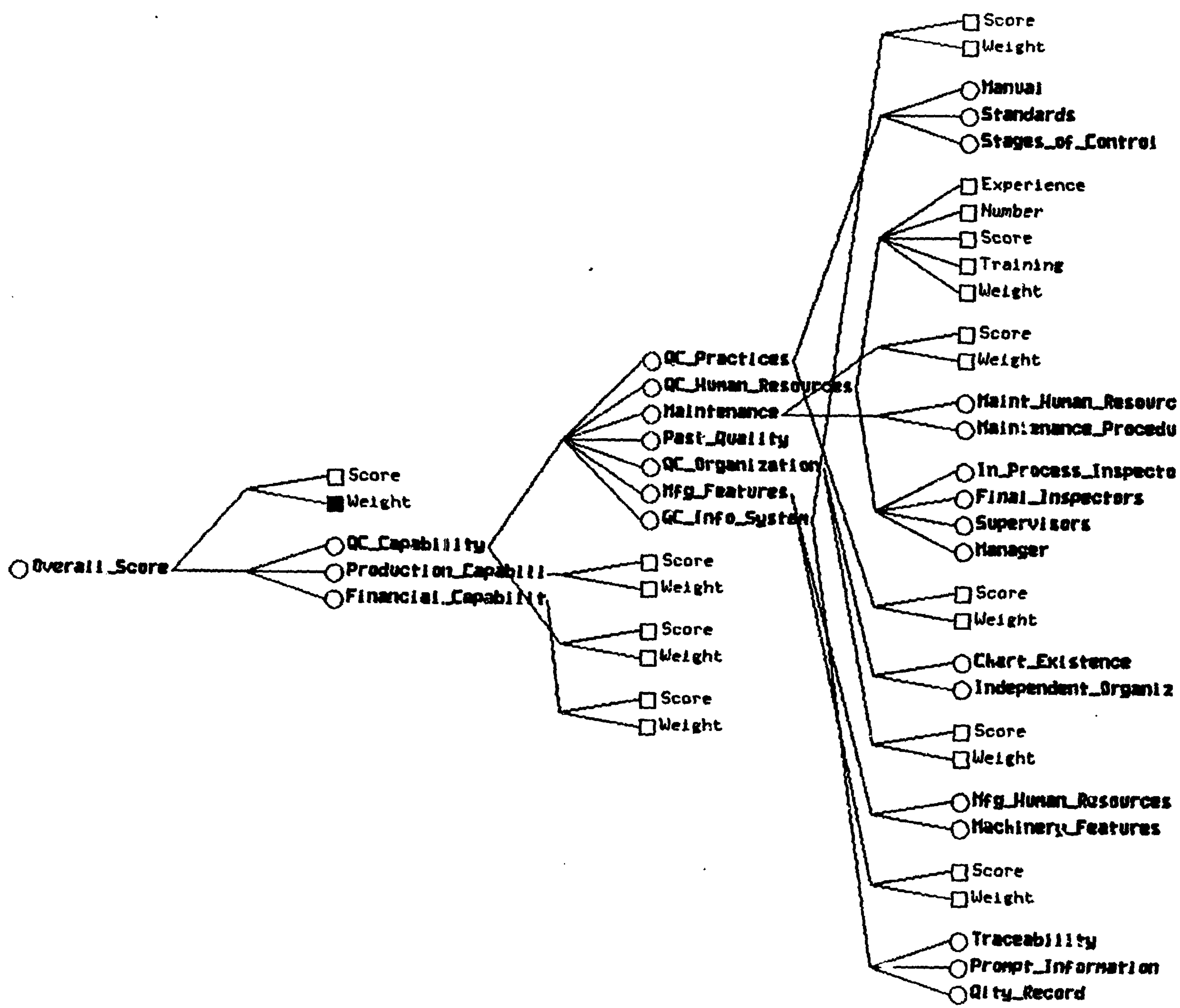
  2. The weights allotted to each of the dependent Objects.

  3. The weight Function or Technique adopted to derive the attribute values.

* Lowest Level Objects will inherit their attribute values from a database (e.g., Technology Level of Machine Used will be obtained from the Machinery and their Technology Levels database).

<u>**HIERARCHICAL OBJECT REPRESENTATION**</u>

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Production_Capabili
Financial_Capabilit
QC_Practices
QC_Human_Resources
Maintenance
Past_Quality
QC_Organization
Mfg_Features
QC_Info_System
Score
Weight
Score
Weight
Score
Weight
Score
Weight
Manual
Standards
Stages_of_Control
Experience
Number
Score
Training
Weight
Score
Weight
Maint_Human_Resourc
Maintenance_Procedu
In_Process_Inspecto
Final_Inspectors
Supervisors
Manager
Score
Weight
Chart_Existence
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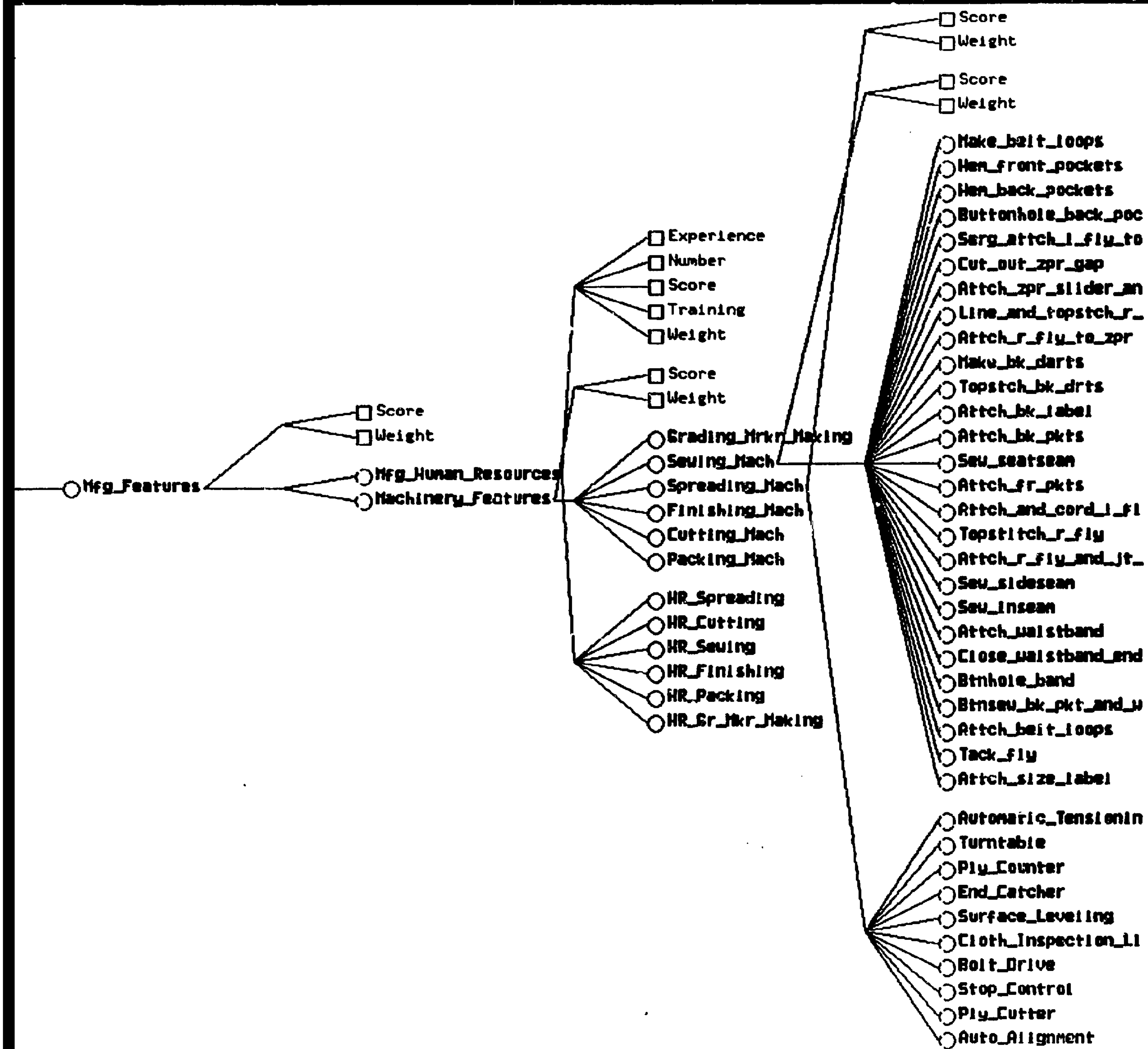
Score
Weight
Mfg_Human_Resources
Machinery_Features
Score
Weight
Traceability
Prompt_Information
Qlty_Record



Mfg_Features
Score
Weight
Mfg_Human_Resources
Machinery_Features
Experience
Number
Score
Training
Weight
Score
Weight
Grading_Mrkr_Making
Sewing_Mach
Spreading_Mach
Finishing_Mach
Cutting_Mach
Packing_Mach
HR_Spreading
HR_Cutting
HR_Sewing
HR_Finishing
HR_Packing
HR_Gr_Mkr_Making
Score
Weight
Score
Weight
Make_belt_loops
Hem_front_pockets
Hem_back_pockets
Buttonhole_back_poc
Serg_attch_l_fly_to
Cut_out_zpr_gap
Attch_zpr_slider_an
Line_and_topstch_r_
Attch_r_fly_to_zpr
Make_bk_darts
Topstch_bk_drts
Attch_bk_label
Attch_bk_pkts
Sew_seatseam
Attch_fr_pkts
Attch_and_cord_l_fl
Topstitch_r_fly
Attch_r_fly_and_lt_
Sew_sideseam
Sew_inseam
Attch_waistband
Close_waistband_end
Btnhole_band
Btnsew_bk_pkt_and_w
Attch_belt_loops
Tack_fly
Attch_size_label
Automatic_Tensionin
Turntable
Ply_Counter
End_Catcher
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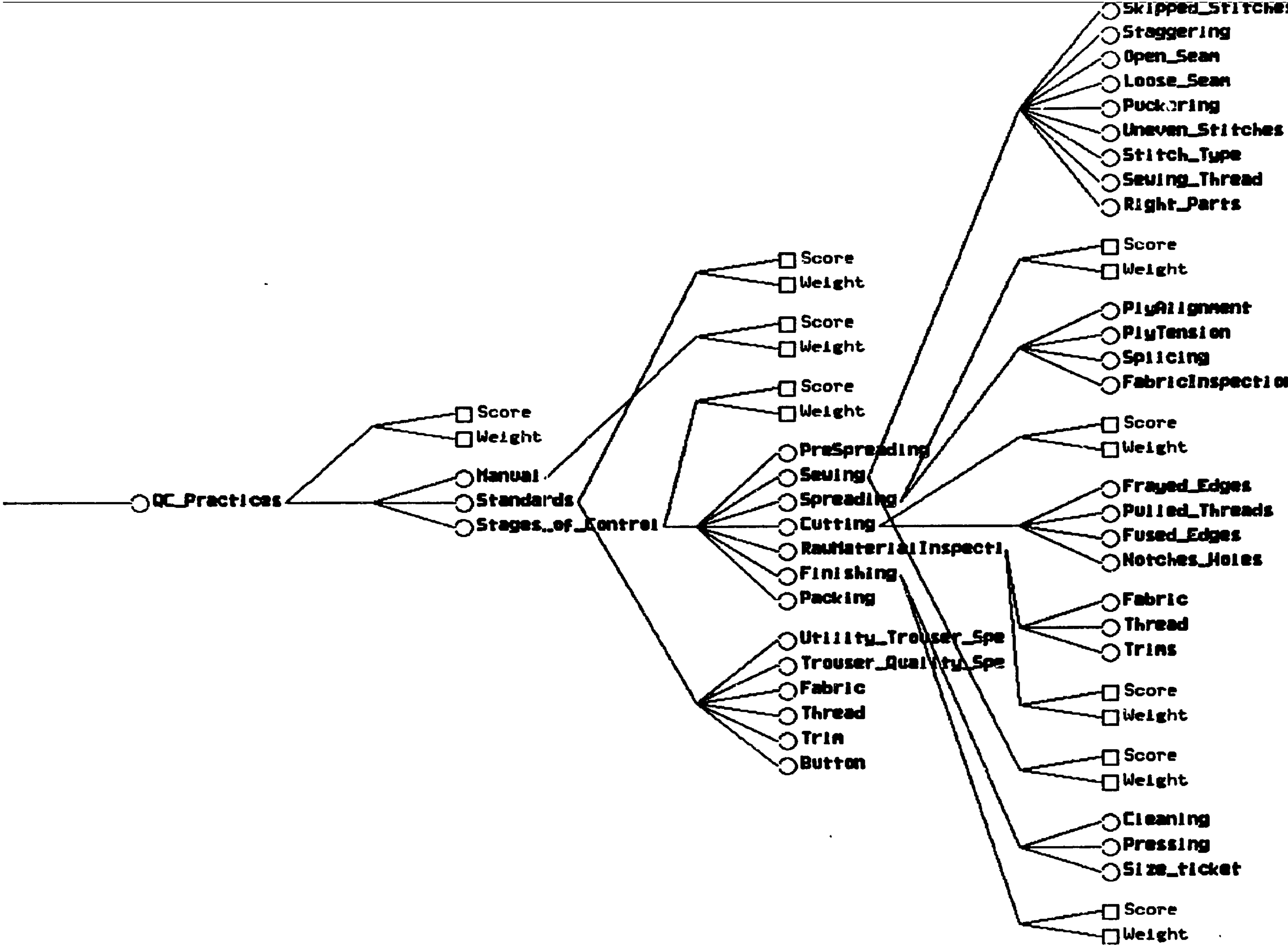
Stop_Control
Ply_Cutter
Auto_Alignment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Manual
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Weight
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PreSpreading
Sewing
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Cutting
RawMaterialInspecti
Finishing
Packing
Utility_Trouser_Spe
Trouser_Quality_Spe
Fabric
Thread
Trim
Button
Skipped_Stitches
Staggering
Open_Seam
Loose_Seam
Puckering
Uneven_Stitches
Stitch_Type
Sewing_Thread
Right_Parts
Score
Weight
PlyAlignment
PlyTension
Splicing
FabricInspection
Score
Weight
Frayed_Edges
Pulled_Threads
Fused_Edges
Notches_Holes
Fabric
Thread
Trims
Score
Weight
Score
Weight
Cleaning
Pressing
Size_ticket
Score
Weight

WEIGHT ASSIGNMENT AND RANKING

Weight Assignment :

* **Expert Opinion**
* **Subjective Weights from Literature**
* **Personal Judgement**

Ranking :

* **Simple Linear Function (at present)**

PROPOSED STRUCTURE OF FORMS FOR GETTING INFORMATION

* Should ask the Contractor about :

1. Production Machinery Details
2. The Number of Quality Assurance Staff
3. Raw Material Testing Procedures
   (Most of the time, DoD does not supply R.M.)
4. Equipment Available for Testing and Q.C.
5. Number of Operators and Production Volumes
6. Company's Financial Information
   (through the Annual Report)
7. Price Break-down
8. Details of Sub-Contracting
9. Defect Percentages in the Past
10. Labor-Management Relationship

Object Networks and Weights
Questionnaire Response

Forms

- Human Resources
  - Manufacturing
    - Operators
    - Supervisors
    - Manager
  - Quality Control
    - Inspectors
    - Supervisors
    - Manager

Sewing Machine Details

Operation:

Operation Sequence#:

Standard Allowable Hours (SAH):

Stitch Type:

MACHINE DETAILS:

Enter the highest Feature# from the attached reference list:

Manufacturer Name	Model#	#of Machines	Stitch Type	Years in Service	Speed(stitch/min)		Dimensions (in ft x ft)	Feature#
					Max	Running		

Reference List for Sewing Machine Features:

Feature#	Feature	
1	Basic Machine	
2	Threadtrimmer Undertrimmer Felling folder	OR OR
3	Cam Control Electronic motor control	OR
4	Automatic workaids e.g., automatic belt loop cut & count automatic feed button sew Programmable electronic motor	 OR OR OR OR
5	Multi-function programmable Fully automatic	OR

Manufacturing Human Resources

OPERATORS

Dept.	Total # of Operators	# of Trainee Operators	Avg. wage $/hr	Piece rate / Hourly rate	Average Experience (in Years)	Training Vendor (Y/N)	Training Technical (Y/N)	Training In-plant (Y/N)	Training School (Y/N)
Grading and Marker Making									
Spreading									
Cutting									
Sewing									
Finishing									
Packing									

How many operators can sew the seatseam?

How many utility operators are there in the sewing dept.?

What is the labor turnover (attrition) rate (in%)?

Manufacturing Human Resources

SUPERVISORS

	Total # of Supervisors	# of Trainee Supervisors	Avg. wage $/hr	Average Experience (in Years)	Training				Education college	
					Vendor (Y/N)	Technical (Y/N)	In-plant (Y/N)	School (Y/N)	2 yr	4yr
Total										
Sewing										

Is there a Training supervisor (Yes/No)?

MANAGER

Experience (years):

Qualifications:

Training:

Salary:

Quality Control Human Resources

INSPECTORS

Category	Total # of Inspectors	# of Trainee Inspectors	Avg. wage $/hr	Piece rate / Hourly rate	Average Experience (in Years)	Training Vendor (Y/N)	Technical (Y/N)	In-plant (Y/N)	School (Y/N)
In-process Inspectors									
Final Inspectors									

How many inspectors can work in both In-process and Final Inspection?

What is the labor turnover (attrition) rate in the QC dept.(in%)?

Quality Control Human Resources

QC SUPERVISORS

	Total # of Supervisors	# of Trainee Supervisors	Avg. wage $/hr	Average Experience (in Years)	Training Vendor (Y/N)	Training Technical (Y/N)	Training In-plant (Y/N)	Training School (Y/N)	Education college 2 yr	Education college 4yr
Total In-process										

Is there a Training supervisor in the QC dept.(Yes/No)?

QC MANAGER

Experience (years):

Qualifications:

Training:

Salary:

To whom does the QC manager report to (give Title):

Attach an Organization Chart of the Company.

Questions

Determine if Standards Followed

Standards

I. Utility Trousers

1. What is the tolerance for the **deviation of the directional line from warp direction** (in inches)?

2. What is the allowed **range of width for belt loops** (in inches)?

3. What is the **stitch type** for **sewing seatseam?**

4. What is the **tolerance** for the **alignment of seat and crotch seams** (in inches)?

II. Quality of Utility Trousers

1. Do you have your own Quality Control manual?

1a. Does it include all operations from receiving to shipping?

1b. Are the operators trained with the QC manual?

2. What is the **sample size** for the **dimensional conformation examination** for this lot?

3. What is the **sample size** for **end-item examination** for this lot?

III. Raw Material Quality

a. Fabric

Please fill in the following information about your fabric

Supplier name:

	Warp	Filling
Minimum Breaking Strength (lbs)		
Minimum Tearing Strength (lbs)		
Minimum Yarns per inch		
Maximum Shrinkage (%)		

b. Trim

Please fill in the following:

Thread supplier:

Zipper supplier:

Button supplier:

Splices or knots allowed per 1000 yards of thread:

Maximum allowed elongation of the thread (in%):

Maximum allowed shrinkage for zipper tape (in%):

Minimum number of cycles before failure for zipper:

Minimum compressive strength of buttons (in lbs):

IV. Standards / Manuals

What standard / manual do you follow for these items:

1. Utility trouser
2. Quality of utility trousers
3. Fabric
4. Thread
5. Zipper
6. Button
7. Packaging and shipping

Current Efforts

* Software Implementation

  Nexpert Object

* Database Additions

* Testing/Refinement

* Delivery

* Extension to Other Garments

Acknowledgements

Research Investigator:
Dr. Howard Olson

Research Technician:
Mr. Dale Stewart

Graduate Research Assistant:
Mr. N. Sambasivan

Machinery Manufacturers

AMTC Steering Committee

AAMA Gov't Contracts Committee

AAMA

Questionnaire Respondents

DLA

DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK FOR CONTRACTOR EVALUATION

QUESTIONNAIRE

JUNE 1989

Please note: **Neither your name nor that of your company will be published or released to anyone.** All the information will be used for analysis only.

Please return the questionnaire to:

Dr. Sundaresan Jayaraman
School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Tel: 404/894-2490
FAX: 404/894-8780

Research Background

Georgia Tech has undertaken research in the School of Textile Engineering aimed at developing a knowledge-based system to aid the source selection process in apparel procurement. A knowledge-based framework (commonly referred to as an expert system) is a computerized, intelligent decision-making tool that will assist apparel manufacturers in evaluating potential contractors for awarding contracts. The key to the development of such a system is the knowledge base, *i.e.*, the criteria, rules and information on which contracts are awarded. The people involved in the decision-making process are the human experts and their participation is vital to the success of the research endeavor.

The Questionnaire

The purpose of the enclosed questionnaire is to solicit your expert opinion on source selection based on your experience. The listed questions may miss some points that you feel are important. You are invited to correct this by adding comments freely. Expected results from analysis of returned questionnaires include identifying important evaluation factors and assigning probability rankings to the various factors. Soundness of the probability rankings is directly proportional to the number of responses returned to Georgia Tech. Thus, your input is extremely valuable and urgently needed.

In return for your participation, you will be offered the opportunity to receive a copy of the results of the questionnaire. See the end of the questionnaire for more details. Also, if another person in your organization can offer their experience to this questionnaire, please notify us to secure additional copies or copy this one for them. Thank you for assisting us in reaching as many experts as is possible.

Research Sponsor

This research is being sponsored by the Defense Logistics Agency (DLA) in the Department of Defense. The DLA procures approximately $1.6 billion worth of apparel every year. If a reliable predictor of contractor performance could be developed, then contract awards could be based on greatest value, including delivery and quality. This is in contrast to the current practice of awarding contracts to the low cost bid bidder. Such an informed and knowledge based approach to procurement would not only help the government, but would also have an overall beneficial effect on the apparel industry. The computer programs will be made available to you and your company for your use.

FEBRUARY 15, 1990

GEORGIA TECH

KNOWLEDGE BASED FRAMEWORK FOR TROUSER DEFECTS

ANALYSIS OF DEFECTS IN TROUSER MANUFACTURING: DEVELOPMENT OF A KNOWLEDGE-BASED FRAMEWORK

Research sponsored by:

U. S. Defense Logistics Agency

(DLA900-87-D-0018 CLIN 0007)

Principal Investigator: Dr. Sundaresan Jayaraman
Research Investigators: Dr. Krishna Parachuru
Dr. Phiroze Dastoor
Graduate Research Assistant: Mr. K. Srinivasan

Georgia Tech Project #: E-27-637

Georgia Institute of Technology
School of Textile Engineering
Atlanta, GA 30332

(404) 894-2490

November 1988 - January 1990

SJ-TR-DEFE-FEB-15-90

ANALYSIS OF DEFECTS IN APPAREL MANUFACTURING: DEVELOPMENT OF A KNOWLEDGE - BASED FRAMEWORK

NEED FOR THE RESEARCH :

* High Quality, Defect-free Apparel Manufacturing:
  Crucial Necessity to Compete
  Effectively Against Imports

* Superior Product Quality fetches:
  Premium Price
  Higher Customer Satisfaction
  Consistent Consumer Demand

* Software-aided Defect Classification & Diagnosis:
  Easily Accessible and Logically
  Organized
  Knowledge from:
    Books
    Questionnaires
    Industry Experts

ADDITIONAL BENEFITS :

* Insight into Optimization of:
    - Inspection Assignments and Procedures
    - Sampling Methods

* Suggest Prioritized List of Remedies for Repeatedly Occurring Faults

* Pinpoint Likely Causes for Trends in Defect Occurrence

* Software Useful For:
    - Training New Employees
    - Introducing New QC Standards
    - Precise Threshold Levels in Inspection

* Ultimately,
    Useful in Closed-Loop On-Line QC/tracking System

OBJECTIVES :

* Build Knowledge-Based Defects Analysis and Classification Software to:

    Diagnose Defects in Fabric and Apparel Manufacturing

    Suggest Plausible Remedies

    Keep Cumulative Track of Individual Defects

    Compile Defect Reports for Material Suppliers and Sub-Contractors

* Initial Focus on Important Domain of Trouser Manufacturing:

    Significant Yet Manageable Segment of the Apparel Market

SCOPE :

* *Phase I* :

Assemble Knowledge and Data on Different Types and Classes of:

Fabric Defects
Faults from Sewing
Trim Defects
. . . . .

Assess Economic Impact

Formalize Knowledge into Software Model

Sources:

MIL Specs [1488, 87062A, . . .]
Apparel Industry Magazines
Computer Science Literature
Questionnaires

* *Phase II* :

Software Implementation of Defects Classification and Analysis Scheme

Series of Prototypes with Continuous Testing and Enhancement

Begin Design of User Interface

* *Phase III* :

Field Test Final Prototype With Group of Experts

Refine Performance of Software Framework

Complete User Interface

Write User Manual

Deliver Software to DLA and Industry

Possible Expansion of Knowledge Base to Apparel Market Sectors other than Trousers

TASKS ACCOMPLISHED

1) LITERATURE REVIEW

Sizable Knowledge Base Compiled on Fabric Defects (up to 50% of All Apparel Defects) and Sewing Defects

Sources being reviewed for Sewing Defects and Trim and Finishing Defects

Other Rule-Based Diagnosis/Analysis Systems: Computer Science Journals

2) QUESTIONNAIRE

Obtain Information from Industry on:
- All Types of Apparel Defects
- Their Economic Impact

Covers Analysis and Classification of Defects in:
- Fabric
- Trim
- Cutting/Sewing Processes
- Finishing
- Packing

AAMA Government Contracts Committee Meeting, March 1989
AMTC Steering Committee: Refinement

20 Pages.

Through AAMA, mailed to over 500 Companies. Only Small Number Returned

3) PLANT VISITS

Several Apparel Plants Visited:
- Insight into Apparel Manufacturing and QC Practices

Valuable Information on:
- Defects Occurrence and Grading
- QC Standards
- Acceptability Norms

Contacts Made Helpful in Final Software Testing and Refinement

4) SOFTWARE DESIGN, DEVELOPMENT

Hardware, Software Choices Made:
- Sun Workstations With UNIX
- Commercial Expert System Shell
  - (Nexpert from Neuron Data)

Rules + Object-Oriented Programming for:
- Defect Representation and Analysis
  - and Classification
- Link to Database System for:
  - Tracking Defect Occurrence
  - Keeping Cumulative Statistics

- Knowledge and Data Collated from Various References

- Knowledge Organized According to:
    - Appearance, Salient Features
    - Size, Shape
    - Direction
    - Mode of Occurrence

- Tabular Forms Expressible as Rules and Hierarchical Relationships, in Software Model

- First prototype deals with:
    - Raw and Finished Fabric Defects from Viewpoint of:
        - Finished Fabric Inspection
        - Inspection at Spreading/Cutting

- Software Implementation of First Prototype

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Software Implementation of First Prototype

<u>Summary of the Analysis of Responses to the Questionnaire</u>

	Average	Range
Number of responses	10	
% Defective trousers	2	0.4-4
%Contribution of fabric defects	55	40-75
%Price realization for defective trousers	40	20-75
Annual Turnover (million $)	45	12-280

Computer assistance in quality control: Three of the 10 companies reported having computerized systems for collecting data about defects.

Training for Quality Inspectors: Most respondents did <u>not</u> have any formal training for quality inspectors.

Significant defects:

1. Shade variation in fabric
2. Missing warp threads
3. Filling defects
4. Soiled garments
5. Skipped stitches
6. Seam Puckering

Fabric Defects Analysis System (FDAS):

A knowledge-based framework for analysis of defects in woven textile structures

Correct identification of the defects

Timely information

Correct remedial action

Shortage of experts

High pay-off

- Defective goods fetch only 50%
- Long term image affected

The System Should:

* Perform the diagnosis in a short time
* Provide different levels of abstractions of the diagnosis, depending on the user needs
* Be highly modular
* Allow the user to alter the output depending on requirements
* Allow pictorial representation of defects

1. Identification - determining the problem characteristics.

2. Conceptualization - finding concepts to represent knowledge.

3. Formalization - designing structures to organize knowledge.

4. Implementation - formulating rules that embody knowledge.

5. Testing - validating rules that embody knowledge.

1. The chosen method of knowledge representation should explicitly show the function of the knowledge - whether it is knowledge about the domain, knowledge used in diagnosis, or control knowledge.

2. The domain knowledge should be separate and should be easily manipulated by the inference mechanism rather than being built into it.

3. It must be easy to add or remove knowledge.

4. Multiple use of the knowledge-base must be possible.

5. The part suggesting the remedies must be separate from the diagnosis segment.

Current literature on defects analysis either just lists the defects alphabetically or classifies them according to the origin of the defect.

This is a serious shortcoming if one wants to refer to these literature to find the exact defect in a fabric and identify its origin, since the basic structure of knowledge in these presupposes knowledge of the exact defect that is present and its origin.

An alternate way of classifying the defects in the textile materials, based on the visual attributes of defects, will overcome this shortcoming.

Knowledge Representation

Hierarchy of classes

Class Hierarchy for Fabric Defects in Current Software Prototype :

- FABRIC DEFECTS
  - POINT
  - LINE
  - AREA

- DEFECT CHARACTERISTIC
  - DEFECT SIZE
  - DEFECT APPEARANCE

- DIRECTION
  - LENGTHWISE
    - CONTINUOUS ALONG LENGTH
    - PARTIALLY ALONG LENGTH
  - WIDTHWISE
    - FULLY ACROSS WIDTH
    - PARTIALLY ACROSS WIDTH
  - OTHER

- MODE OF OCCURRENCE (L, W)
  - ISOLATED
  - RANDOMLY DISTRIBUTED
  - REGULARLY REPEATING
  - CONTINUOUS

EXAMPLES: FABRIC DEFECTS

1) Typical Point Defect: *Knots*

Defect Size:
At Least Twice the Yarn Diameter

Defect Appearance:
Large Knot Raised From Fabric Surface

Defect Direction:
No Particular Orientation (Other)

Defect Mode of Occurrence (Length):
Isolated
Random

Defect Mode of Occurrence (Width):
Isolated

2) Typical Line Defect: *Missing Pick*

Defect Size:
Single Yarn Diameter

Defect Appearance:
Widthwise Gap

Defect Direction:
Fully Across Width

Defect Mode of Occurrence (Length):
Isolated

Defect Mode of Occurrence (Width):
Continuous

3) Typical Area Defect: *Shade Variation in Fabric Dyeing*

Defect Size:
Variable; Patch or Streak

Defect Appearance:
Ill-Defined, Irregular Areas of Different Shades

Defect Direction:
No Particular Orientation (Other)

Defect Mode of Occurrence (Length):
Isolated
Random
Regularly Repeating
Continuous

Defect Mode of Occurrence (Width):
Isolated
Continuous

CL-Continuous-Lengthwise
PL-Partial-Lengthwise
CW-Continuous-Widthwise
PW-Partial-Widthwise
NPO-No Preferred Orientation
I-Isolated
R-Random
Re-Regular
C-Continuous

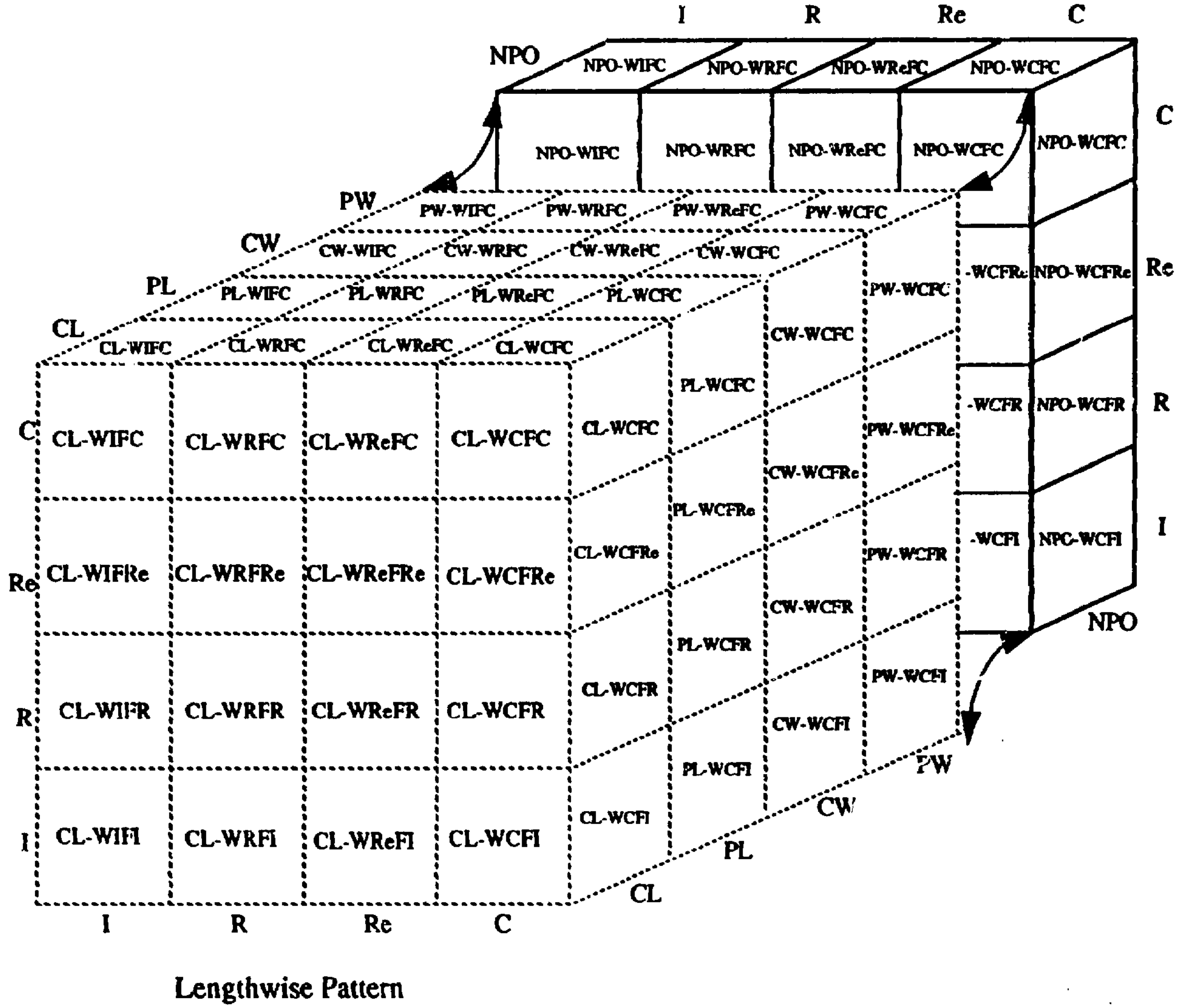


Figure 4.2 Classification of Fabric Defects According to Key Characteristics

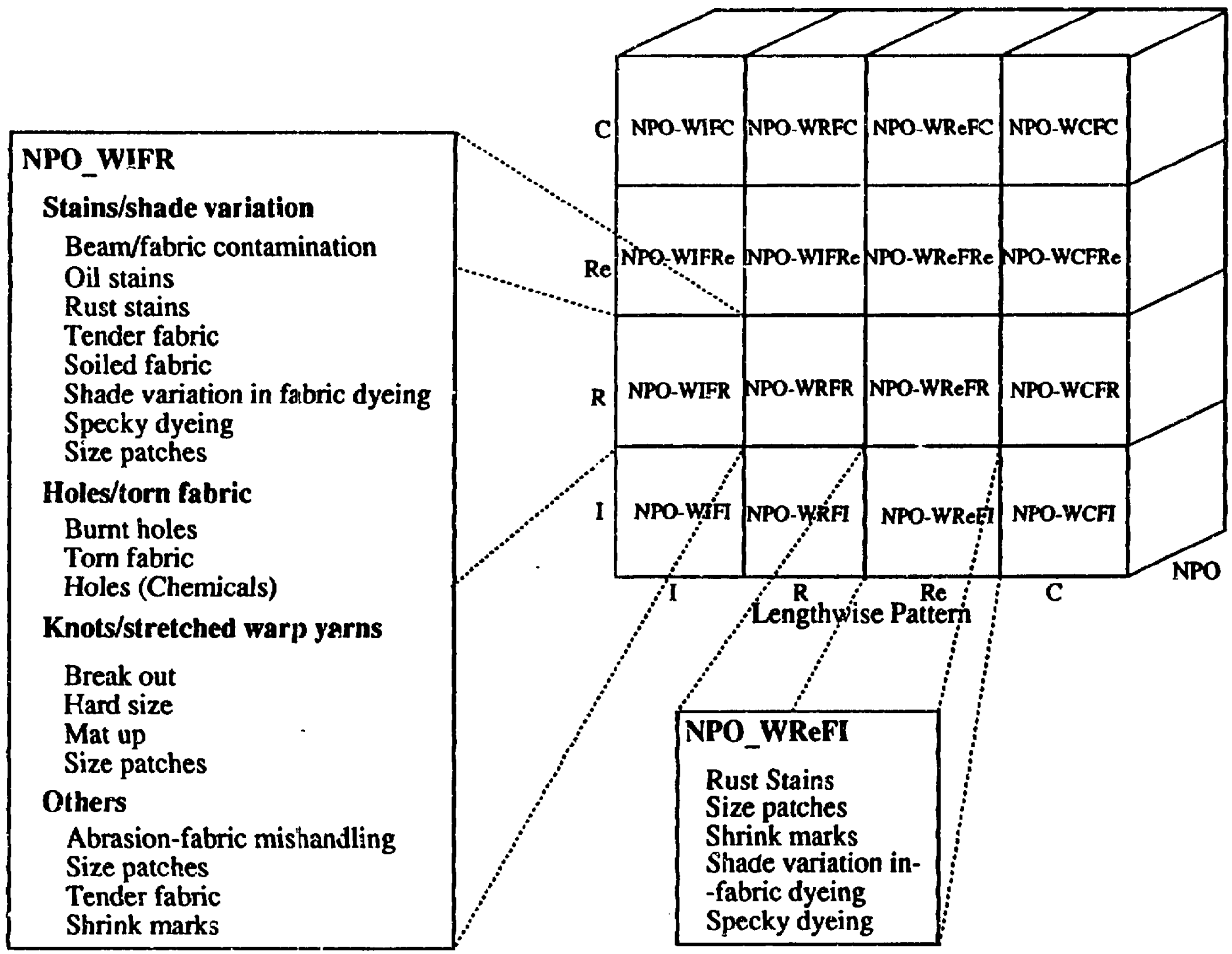
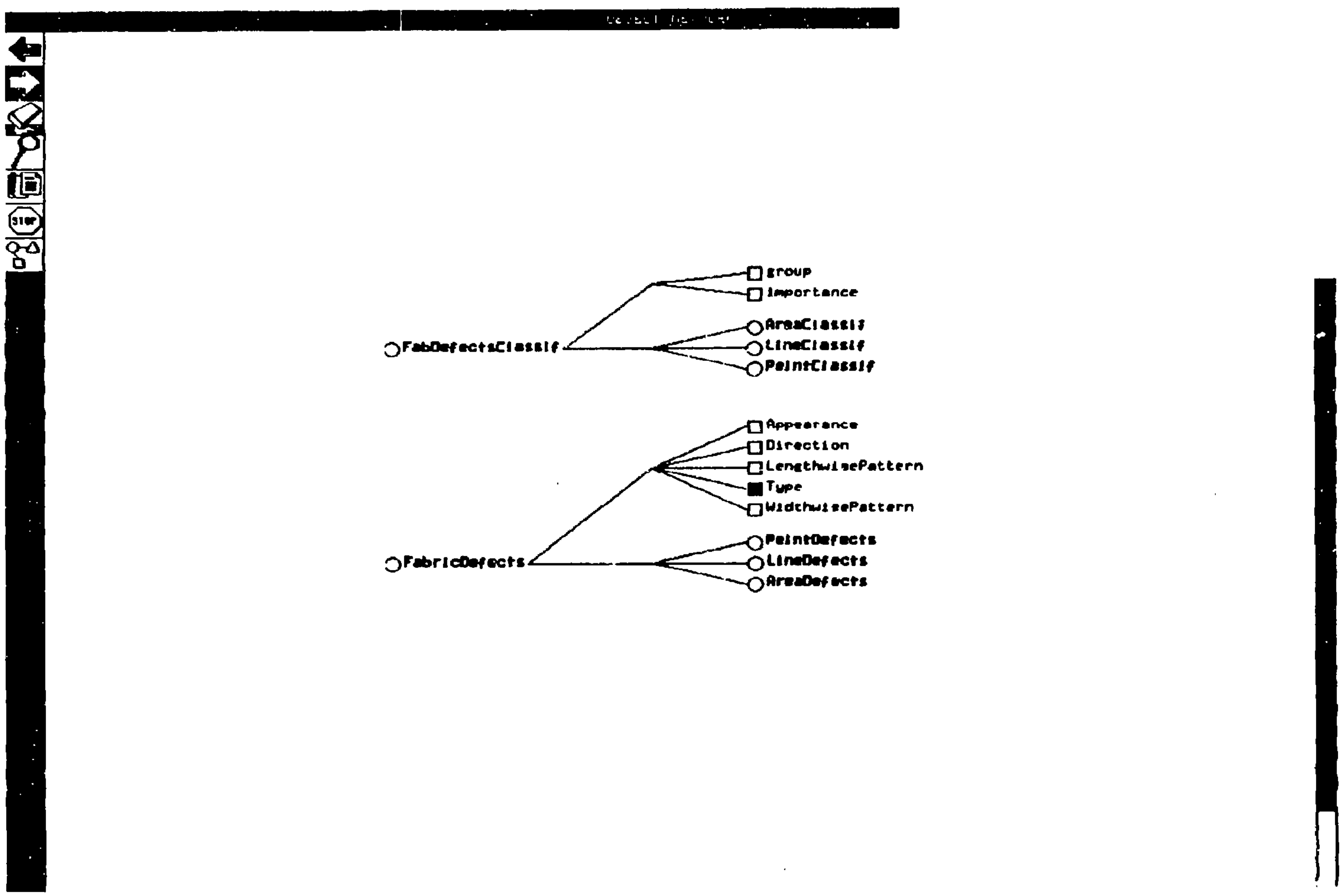
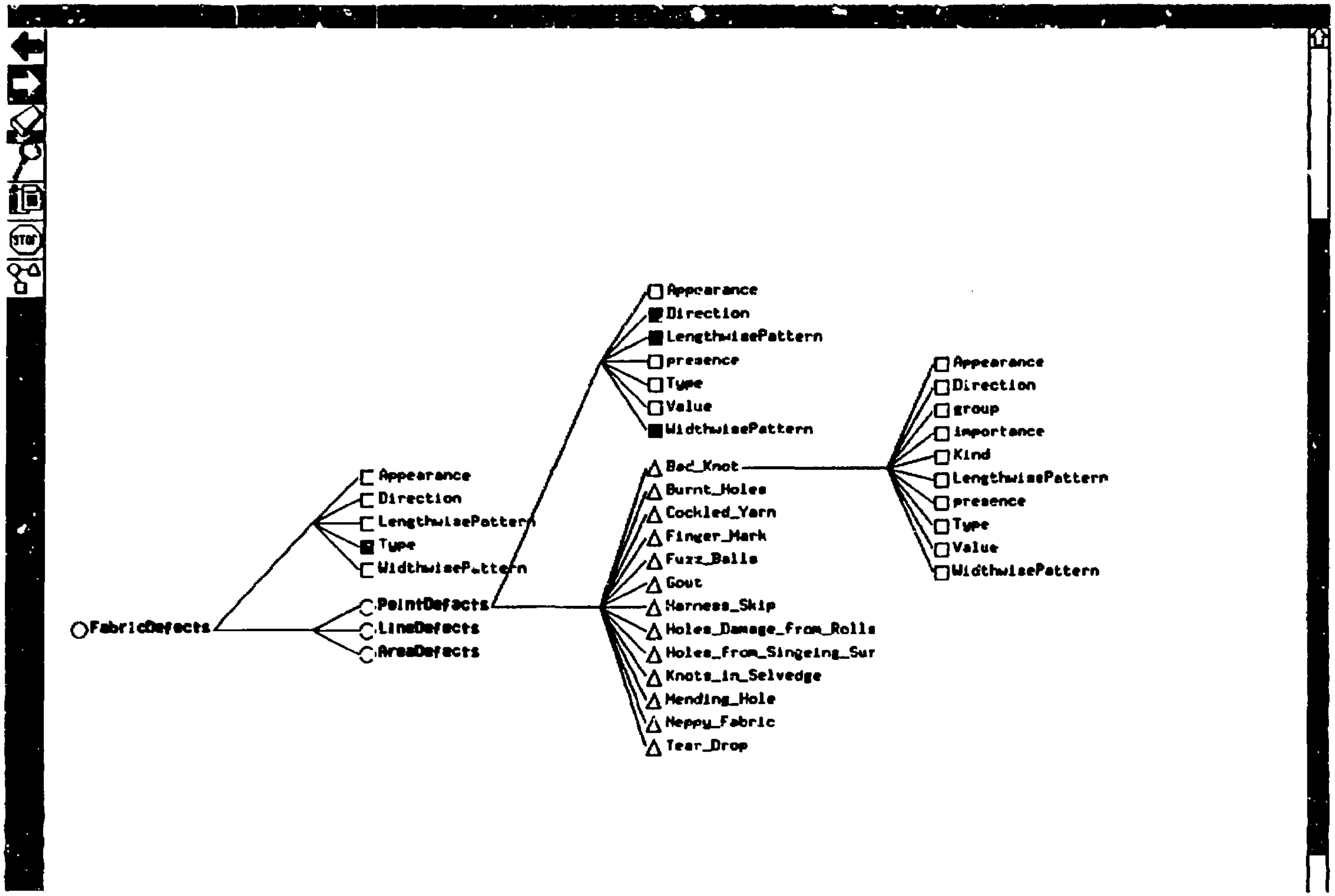


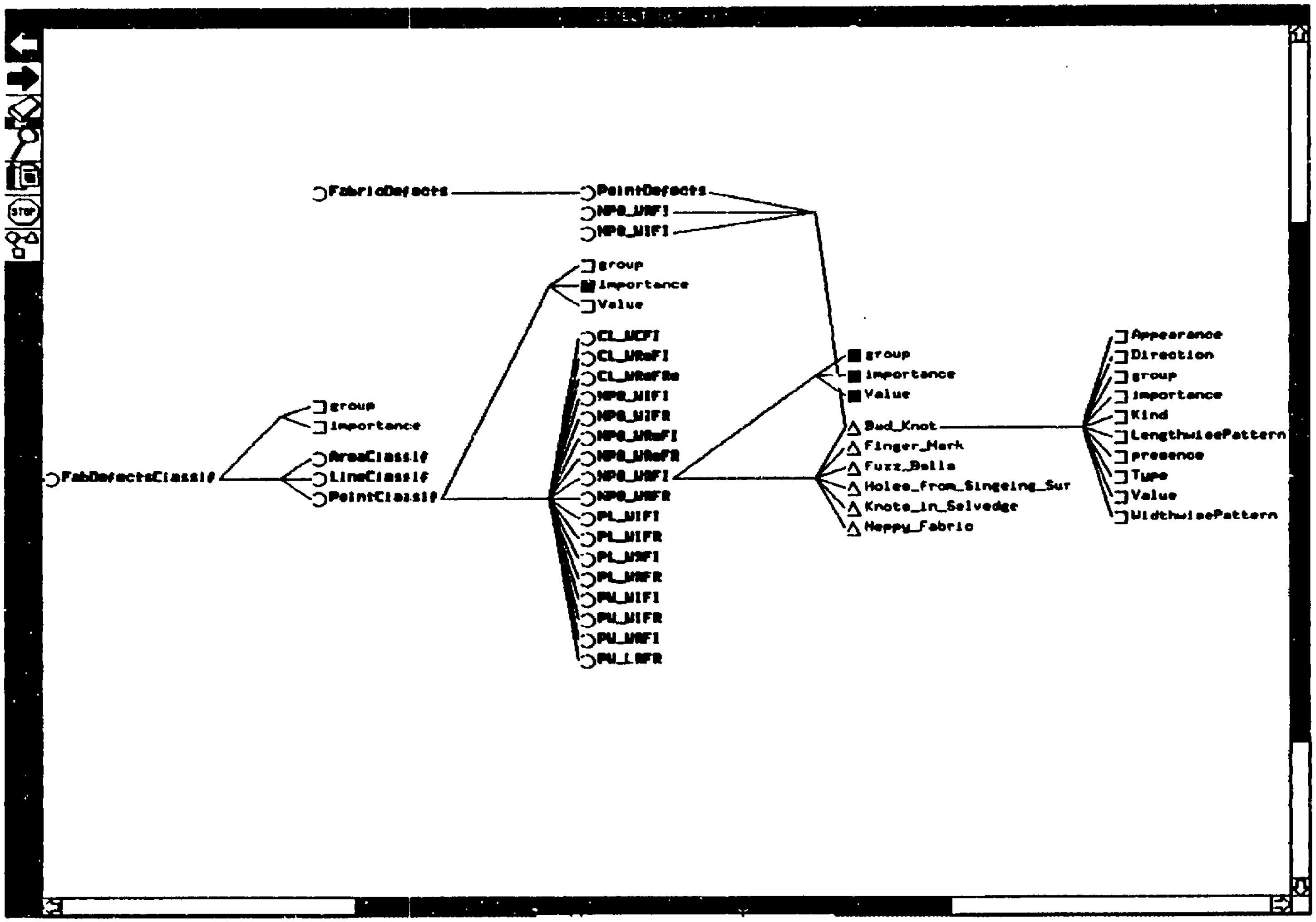
Figure 4.3 Subclassification of Classes with more than Eight Defects



Top Level of the Two Class Hierarchies in FDAS



Class Hierarchy for Representing Fabric Defects



Class Hierarchy for Inference Control

List of Fabric Defects in FDAS

Point Defects

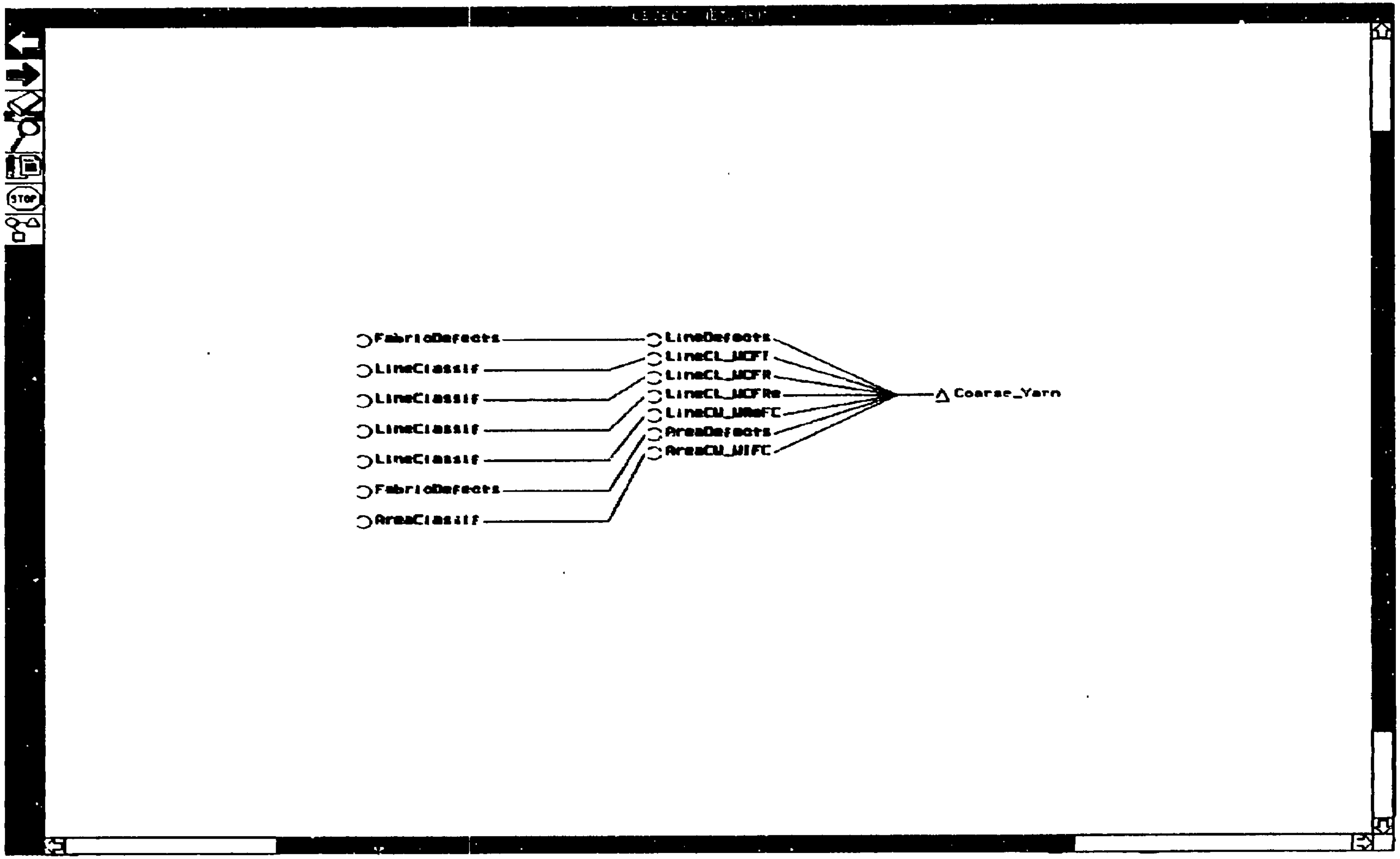
1. Burnt hole
2. Cockled yarn
3. Finger mark
4. Fuzz balls
5. Gout
6. Harness skip
7. Holes - damaged rolls
8. Holes - singeing
9. Knots in selvage
10. Large knots
11. Long knot tails
12. Mending hole
13. Neps
14. Tear drop

Line Defects

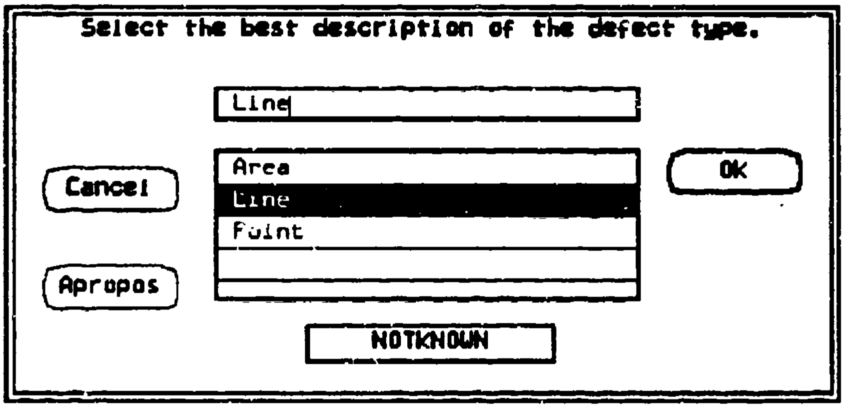
1. Abrasion
2. Broken end
3. Broken pick
4. Coarse yarn
5. Corded selvage
6. Crackers
7. Crease mark
8. Double end
9. Double pick
10. End out
11. Float
12. Hanging thread
13. Harness skip
14. Jerk-in
15. Kinky yarn
16. Looping pick
17. Misdraw
18. Missing pick
19. Mixed yarn - blend
20. Mixed yarn - Twist
21. Oily/dirty yarn
22. Reed mark
23. Seam mark
24. Shade variation yarn
25. Slack end
26. Slack pick
27. Thin yarn
28. Tight end
29. Tight pick
30. Uneven yarn
31. Warp burl
32. Warp streak
33. Yarn shade variation
34. Yarn slubs
35. Waste in filling (on loom)

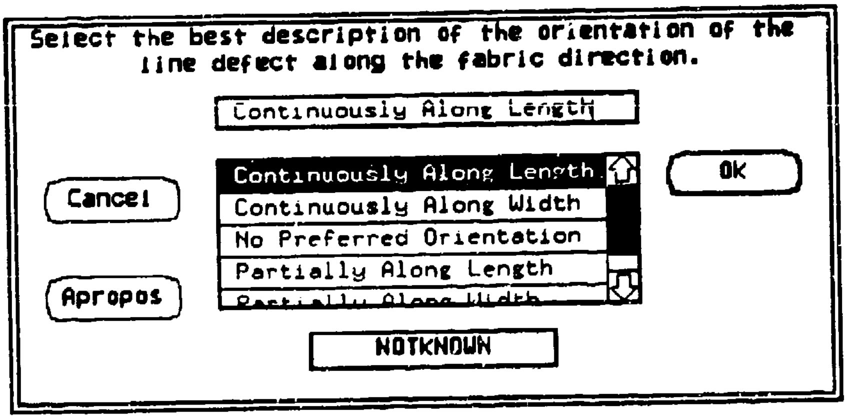
Area Defects

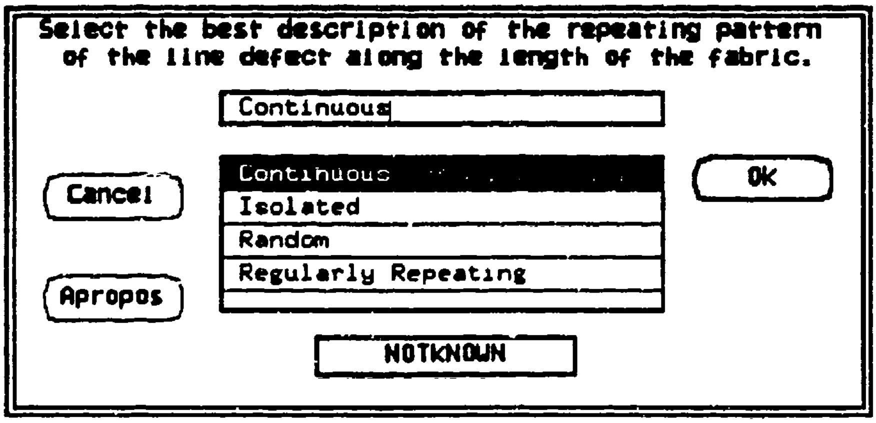
1. Abrasion
2. Apron mark
3. Beam/fabric contamination
4. Bowed filling
5. Break out
6. Burnt holes
7. Coarse yarn
8. Color bleeding
9. Crease mark
10. Filling bar
11. Finishing bar
12. Hairiness
13. Hard size
14. Holes
15. Mat-up
16. Oil stain
17. Puckered fabric
18. Reediness
19. Rolled selvage
20. Rust stain
21. Selvage tails
22. Shade variation fabric
23. Shade variation yarn
24. Shrink mark
25. Shuttle smash
26. Soiled fabric
27. Specky dyeing
28. Temple mark
29. Tender spot
30. Thick place
31. Thin place
32. Torn cloth
33. Uneven fabric width
34. Uneven finish
35. Uneven yarn
36. Variable selvage dyeing
37. Wavy fabric
38. Wavy selvage
39. Wrong pattern

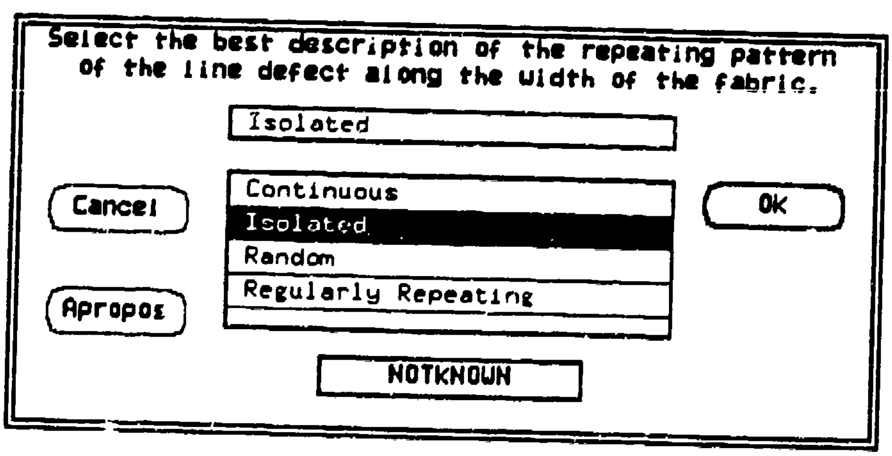


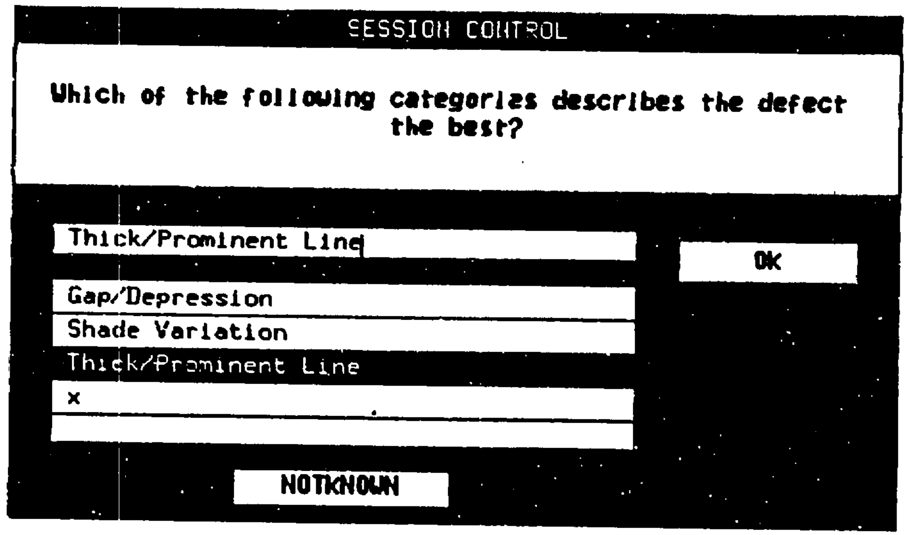
Different Modes of Occurrence of Coarse Yarn

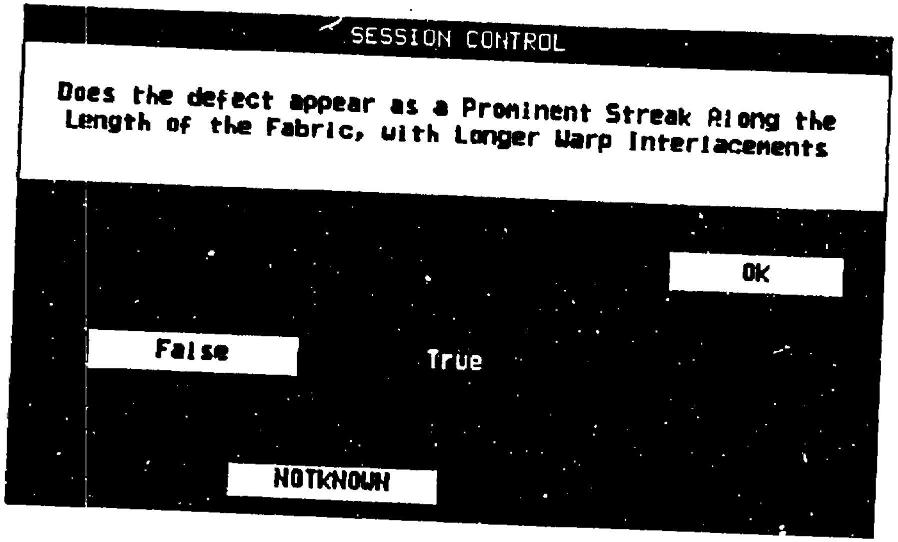

Select the best description of the defect type.
Line
Cancel
Apropos
Area
Line
Point
OK
NOTKNOWN


Select the best description of the orientation of the line defect along the fabric direction.
Continuously Along Length
Cancel
Apropos
Continuously Along Length
Continuously Along Width
No Preferred Orientation
Partially Along Length
OK
NOTKNOWN


Select the best description of the repeating pattern of the line defect along the length of the fabric.
Continuous
Cancel
Continuous
Isolated
Random
Regularly Repeating
OK
Apropos
NOTKNOWN


Select the best description of the repeating pattern of the line defect along the width of the fabric.
Isolated
Cancel
Continuous
Isolated
Random
Regularly Repeating
OK
Apropos
NOTKNOWN


SESSION CONTROL
Which of the following categories describes the defect the best?
Thick/Prominent Line
OK
Gap/Depression
Shade Variation
Thick/Prominent Line
x
NOTKNOWN


SESSION CONTROL
Does the defect appear as a Prominent Streak Along the Length of the Fabric, with Longer Warp Interlacements
OK
False
True
NOTKNOWN

APROPOS #1

The defect is confirmed as Slack End.

Probable Causes:

An end which is running out or broken; tension on the end is held for a while by adjacent ends and gradually released as it runs up.

Suggested Remedy:

If the yarn is too hairy, increased size pick-up may be necessary.

Using heavier dropwires will ensure the stoppage of loom if an end breaks.

Reduce the density of dropwires at electrobars if necessary.

Reduce crossed ends to ensure quicker release of broken ends.

Reduce lost ends in preparation when these are the cause.

Close

Keep

Level 1 : Rule 61
If **|FabricDefects|.Type** is *"Line"*
Then **LineClassif** is confirmed.
And |**PointDefects|.presence** is set to FALSE
And **|AreaDefects|.presence** is set to FALSE
And **PointClassif.group** is set to FALSE
And **AreaClassif.group** is set to FALSE

Level 2: Rule 55
If there is evidence of **|LineClassif**|
And |**LineDefects|.Direction** is *"Continuously Along Length"*
And **|LineDefects|.LengthwisePattern** is *"Continuous"*
And **|LineDefects|.WidthwisePattern** is *"Isolated"*
Then **LineCL_WCFI** is confirmed.
And **|LineClassif|.group** is set to FALSE
And **|LineCL_WCFI|.group** is set to TRUE
And 100 is assigned to **|LineCL_WCFI|.importance**

Level 3 : Rule 127
If there is evidence of **|LineCL_WCFI|.group**
And **|LineCL_WCFI|.SubGroup** is *"Thick/Prominent Line"*
And there is evidence of *Lengthwise_Prominent_Streak_-with_Longer_Interlacement*
Then **Slack_End.presence** is confirmed.
And **<|LineDefects|>.presence** is set to FALSE
And Show "causes/slack_end" @KEEP=TRUE;@WAIT=FALSE;

Three Levels of Rules for Slack End - a Typical Line Defect

Time in seconds for user interaction with the system

	User Interface	Developer Interface
Fuzz balls	27	164
Coarse yarn	68	461

Profile of FDAS

System name	:	Fabric Defects Analysis System (FDAS)
Domain	:	Textile and apparel manufacturing
Functions	:	Identification of defects in the finished fabrics and suggestion of appropriate remedies
Current state	:	Research prototype
Location of development	:	Georgia Institute of Technology School of Textile Engineering
Software for implementation	:	Nexpert Object
Hardware	:	Sun 386*i*
Similar systems	:	CENTAUR (Aiki 83) CASNET/GLAUCOMA (Szlo 78) GALEN (Thom 83)
Knowledge built into the system	:	Description of fabric defects using visual characteristics; classification of defects using the description; causes and remedies for the defects.
Input to the system	:	Description of the defect.
Output from the system	:	Identity of the defect, possible causes and suggested remedies.
Model used	:	Associational.
Knowledge representation method	:	Hierarchy of classes with multiple inheritance and rules.
Search method	:	Forward chaining rules and early pruning.
Search control	:	Dynamic resetting of the priority of classes of hypothe-

ses. A distinct class hierarchy is used for the control, and the slot-values of these classes are changed by the actions triggered by the firing of rules.

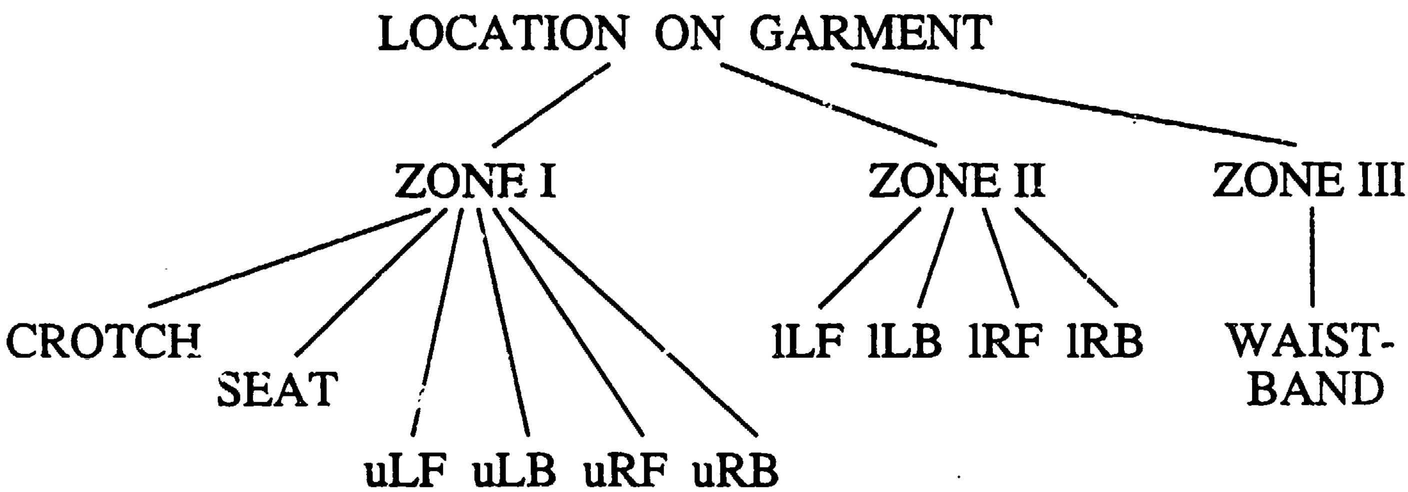
Number of fabric defects included	:	85
Number of rules	:	400
Input method	:	Menu selection using mouse
System output	.	Text windows for the system conclusions and a combination of text and graphical output for explanation of the inference process.
Interaction time	:	User interface : 27 to 164 seconds Developer interface : 68 to 461 seconds

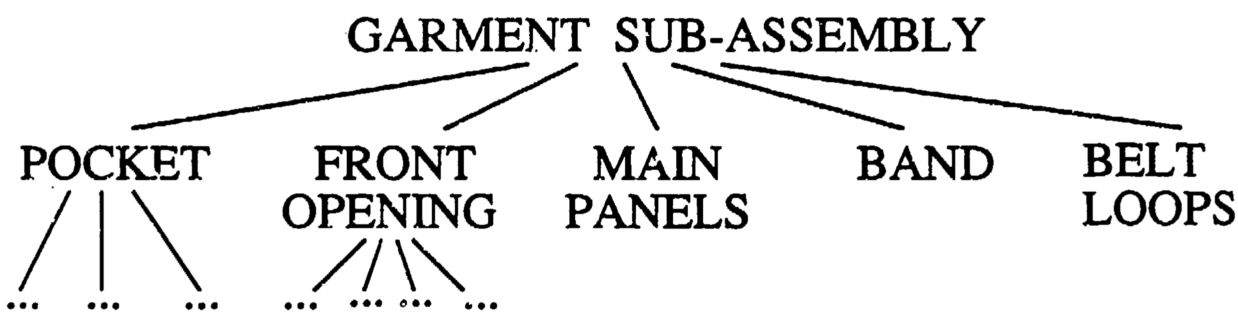
Class Hierarchy (Proposed) for Sewing Defects in Current Software Model:

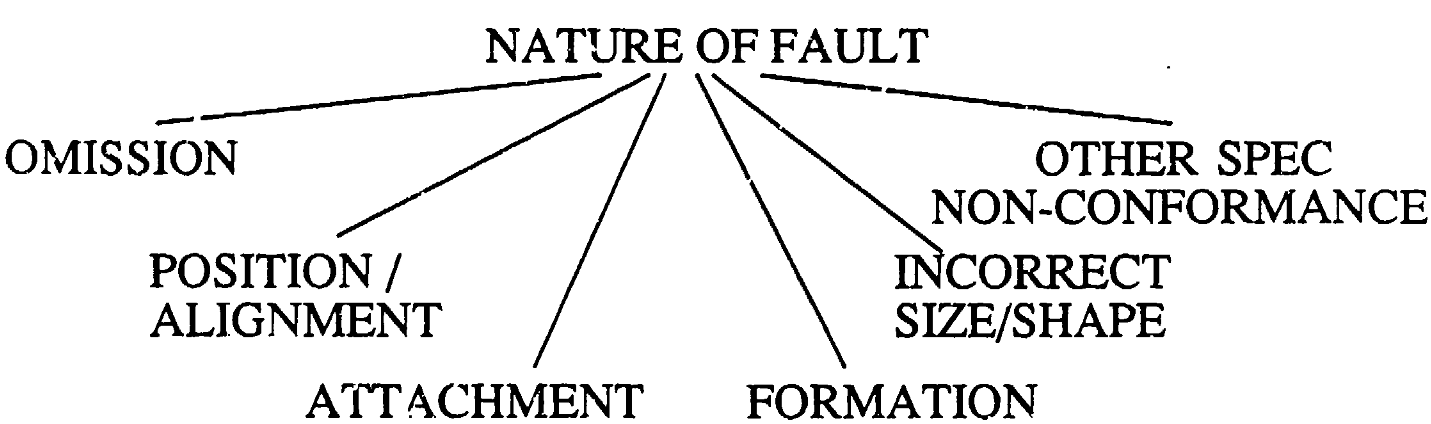
- CONTRIBUTING PROCESS
  - PATTERN / DESIGN
  - SPREADING
  - CUTTING
  - SEWING
    - ...
    - ...
    - ...
    - ...
    - ......
  - PRESSING

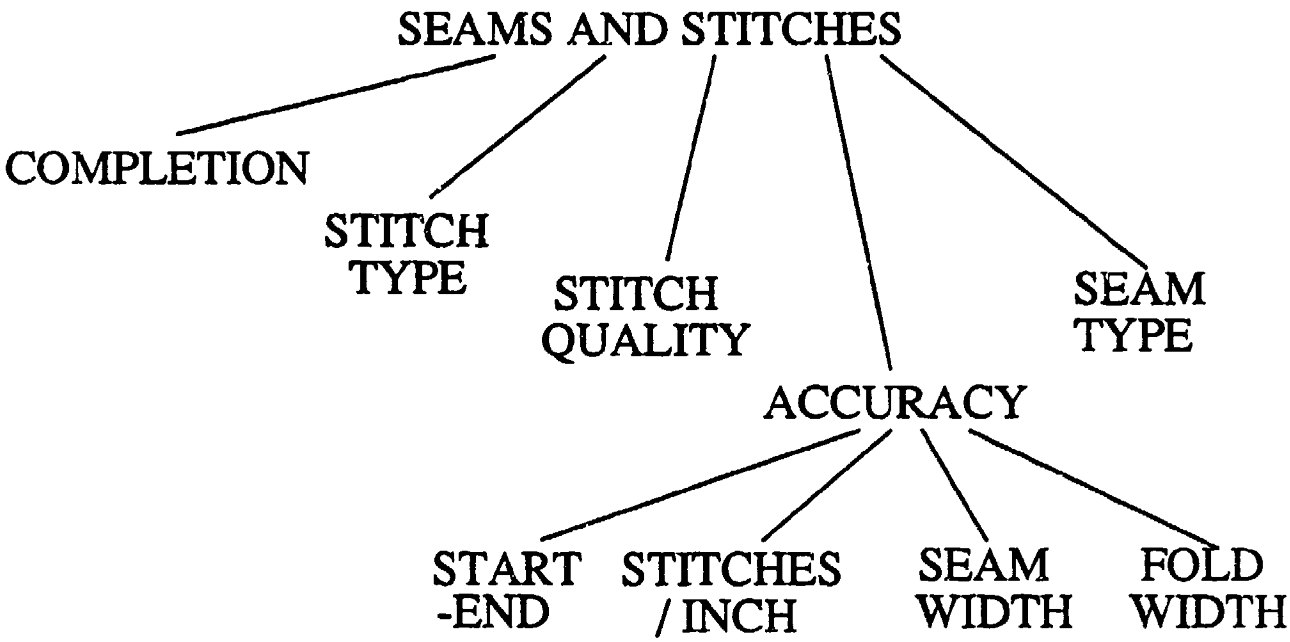
- CONTRIBUTING FACTORS
  - HUMAN
  - MACHINE
  - MATERIAL

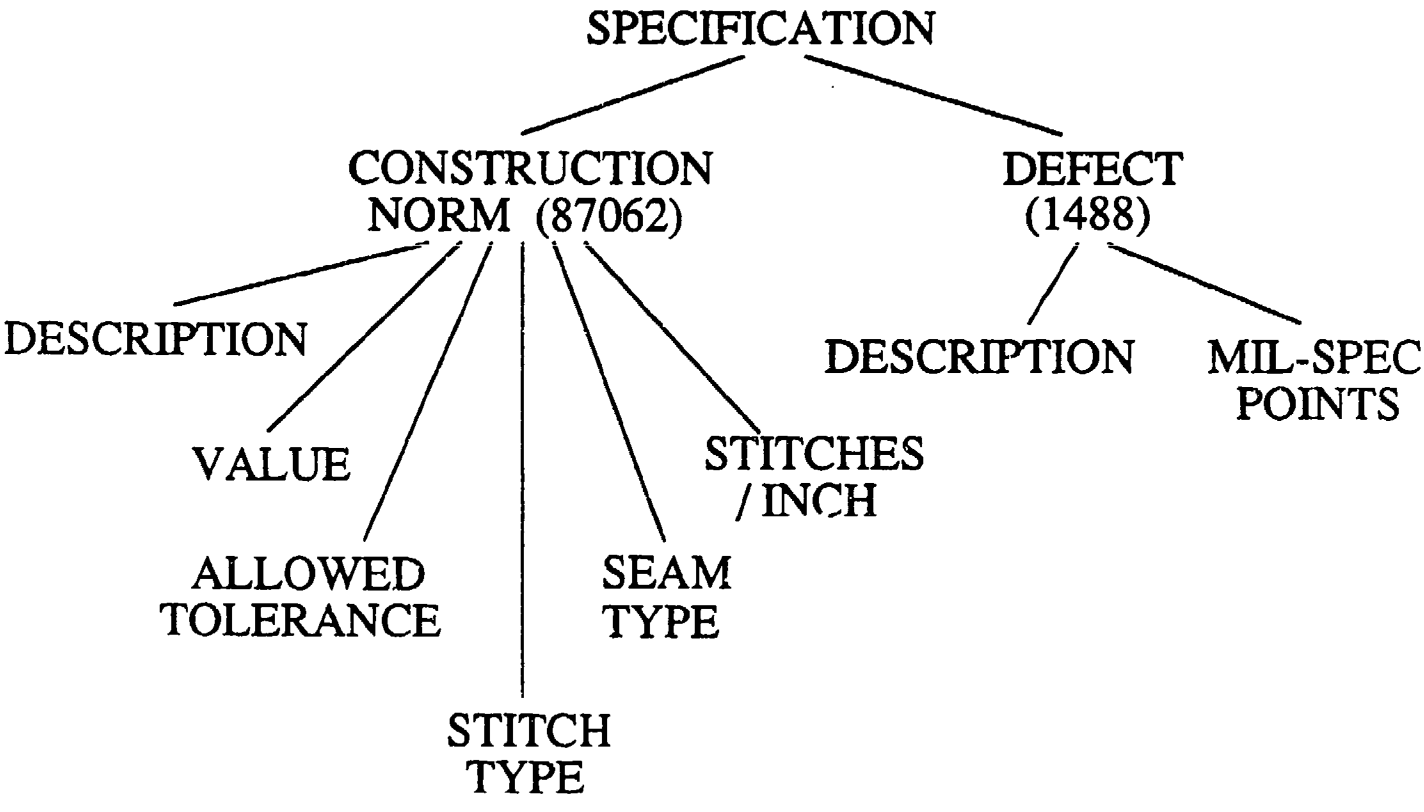
- IMPACT OF DEFECT
  - FIT
  - APPEARANCE
    - VISUAL CHARACTER
    - COLOR MATCHING
    - CLEANLINESS
  - FUNCTIONALITY


LOCATION ON GARMENT
ZONE I
ZONE II
ZONE III
CROTCH
SEAT
uLF uLB uRF uRB
lLF lLB lRF lRB
WAIST-BAND


GARMENT SUB-ASSEMBLY
POCKET
FRONT OPENING
MAIN PANELS
BAND
BELT LOOPS
...


NATURE OF FAULT
OMISSION
POSITION / ALIGNMENT
ATTACHMENT
FORMATION
INCORRECT SIZE/SHAPE
OTHER SPEC NON-CONFORMANCE


SEAMS AND STITCHES
COMPLETION
STITCH TYPE
STITCH QUALITY
ACCURACY
SEAM TYPE
START -END
STITCHES / INCH
SEAM WIDTH
FOLD WIDTH


SPECIFICATION
CONSTRUCTION NORM (87062)
DEFECT (1488)
DESCRIPTION
VALUE
ALLOWED TOLERANCE
STITCH TYPE
SEAM TYPE
STITCHES / INCH
DESCRIPTION
MIL-SPEC POINTS

WHAT WE CAN SAY AT THIS POINT

* Rule-based (or, "Expert System") Software:

    Ideal for Representation of Diagnosis or Analysis Task

    Allows Rapid Prototyping

    Great Simplicity:
    Hierarchical Structure Represented as Classes and Objects

* Raw/Finished Fabric Defects:

    Very Important in Overall Contribution

    Not Really in Apparel Manufacturer's Control

    Importance of Cumulative Defect Statistics:
    Report to Fabric Supplier, Sub-Contractor

* Several User Profiles, System Targets:

  Inspection at Finished Fabric
  Spreading/Cutting Inspection
  Final Garment Inspection

  Variations in Nature of the Task
  Different Time Constraints
  Same Software ??

PROBLEMS ENCOUNTERED

* Questionnaires:

Disappointing response

560 Distributed, Handful of Answers

Useless

Useful

Extremely Useful

Size, Detail and Content Possibly Overwhelming, but All Requested Data Relevant

* Software Speed:

Nexpert Slightly Slow (X Windows)

Solutions Being Sought

WORK IN PROGRESS

* Extend First Prototype (Fabric Defects) to Deal With:
    - Sewing/Assembly Defects
    - Trim/Finishing Defects

* User Interface (Version I)
  Emphasis on:
    - Ease of Use, Help Facility
    - Conceptual Clarity
    - Error Tolerance/Recovery

* Test Software With Panel of Experts from Industry
    - Refine Prototype(s), Prepare Final Version of Software
    - Complete User Interface
    - Write User Manual

* Investigate Possible Extensions to Knowledge Base for Other Apparel Sectors

* Deliver Software, Documentation

POSSIBLE EXTENSIONS

* Build Visual Front-End. Made Up Of Hierarchically-Arranged Sets of High-Quality Images of Defects

Advantages:

- Utilize Superb Human Visual Pattern Matching
- Bypass Tedious Sequence of User Commands to Classify Defect
- Reduce Dependence on User's Verbal Communication Skills

Problems:

- Acquiring Defective Samples Requires Great Cooperation From Textile and Apparel Industry
- Display Speed, Scaling Problem
- Accurate Surface, Color, Texture Resolution

* Extend Knowledge Base:
  Cover Apparel Sectors Other Than
  Utility Trousers

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  Dr. Phiroze Dastoor

  Graduate Research Assistant:

  K. Srinivasan

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* AAMA: Mailing Assistance

* AMTC Steering Committee : Refining the Questionnaire

FEBRUARY 15, 1990

NORTH CAROLINA STATE UNIVERSITY

DEFINITION OF FLEXIBILITY

ANALYSIS OF FLEXIBILITY AND OTHER IMPORTANT CRITERIA FOR EVALUATING ADVANCED APPAREL MANUFACTURING SYSTEMS

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This presentation outlines the work to date on evaluating advanced apparel manufacturing systems. Portions of this research have been presented in Apparel Manufacturer [1, 2, 3] and most recently in The Engineering Economist [4].

Based on interviews and case studies, multiple attribute decision models have been developed for selecting apparel sewing equipment. These models have been constructed using the Analytic Hierarchy Process and point allocation methodologies for arriving at an overall weighted evaluation for each alternative sewing system. These models may be implemented using spreadsheet computer programs or commercially available software packages. These multiple attribute decision models are believed to complement traditional economic models, which are also under development.

1. Hodge, G. L. and J. R. Canada, "Multiple Attributes/Criteria for Evaluating Manufacturing Systems," Apparel Manufacturer, vol. 1. no. 1 (May 1989) pp. 53-57.

2. Hodge, G. L. and J. R. Canada, "Evaluating Advanced Apparel Sewing Equipment/WorkStations," Apparel Manufacturer, vol. 1. no. 2 (Aug. 1989) pp. 55-58.

3. Hodge, G. L. and J. R. Canada, "Evaluating Manufacturing Systems," Apparel Manufacturer, vol. 1. no. 3 (Nov. 1989) pp. 105-111.

4. Hodge, G. L. and J. R. Canada, "Low Cost Microcomputer Software for Non-Traditional Economic Decision Analysis," The Engineering Economist, vol. 35 no. 2 (Winter 1990) pp. 161-167.

FEBRUARY 15, 1990

GEORGIA TECH

CUT ORDER PLANNING FOR TROUSER MANUFACTURING

CUT ORDER PLANNING

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Georgia Institute of Technology
Apparel Manufacturing Technology Center

February, 1990

Sponsor: DEFENSE LOGISTICS AGENCY
Defense Electronics Supply Center
United States Department of Defense

1.0 *Introduction and Scope of Project*

1.1 Introduction

In order to reestablish a competitive position in the international marketplace, the apparel industry is focusing on upgrading its responsiveness to customer needs. Smaller orders are placed in a more dynamic fashion, forcing the efficient production of smaller lots.

Responsive and economical production of military utility trousers depends upon the interaction of many components, one critical component being a workflow control system designed specifically for flexible trouser manufacturing. The cut order planning (COP) process is a dynamic one in that the procedure must respond to the ever changing status of many critical factors such as sales, inventory levels, raw materials, and labor and equipment availability. The variety of sizes, styles, fabrics, and colors induces significant complexity in this problem. Adding to the complexity, and thus potentially increasing total production costs, are such considerations as setup, or changeover costs, the question of appropriate lot sizes, the necessity to meet customer demand, and the importance of making competitive delivery promises.

This project undertakes the study of improving systems for cut order planning and the specific application of the improved approach to trouser manufacturing.

1.2 Scope of the Project

The objective of this project is to investigate appropriate methodologies for cut order planning. First, existing software packages will be examined and their performances comparatively analyzed, utilizing testbed data. Second, a theoretical analysis of the cut order planning process will be performed and appropriate algorithms developed. The approach derived from the theoretical analysis will be implemented in a prototype software package developed for the purposes of experimentation and evaluation of the algorithm.

Two products will result from this research. First will be an understanding of the relative performance of currently available software for cut order planning. Second will be an algorithm implemented in a prototype software package which will be structured for future integration into commercially available software systems.

1.3 Problem Definition

Following is a general description of the cut order planning problem in terms of input, output, and objective.

Given an order to be cut, the input to the problem consists of:
- The sizes required for the order,
- The quantity of each size to be cut,
- The total perimeter inches of each pattern piece to be utilized in the cut,
- The total area of the pattern pieces to be utilized in the cut,
- The front/back sequence (1 or 2 ply per cut), and
- The standards for spreading (marker fixed costs, marker variable costs, cost to copy, minimum and maximum plies, number of sizes per marker, cutting costs, cutting speed, and cutting setup).

The output from the cut order planning process then consists of the following:
- The sizes to be combined in each section of the marker,
- The estimated efficiency of the marker (in per cent of fabric utilization),
- The cutting cost per unit,
- The total perimeter to be cut, and
- The total area to be cut.

The objective of the cut order planning problem is to minimize costs, with a tradeoff to be made between cutting costs and fabric costs. The key decisions to be made are the number of sections required to fill the order, ply height in each section, and which sizes are to be cut in each section. The output of which sizes are to be combined in each section of the marker is passed on to the marker making function for actual determination of the marker itself.

This description of the problem seems to be the one taken by most of the software vendors currently marketing systems for solving the cut order planning problem. However, during the course of this project we will be examining these software systems in more detail, so this description may change. In section 3.0 we will discuss our views of how this problem should be integrated into a shop floor control setting where a more "systems" view of the world is taken.

2.0 *Project Activities*

This project will be conducted in two phases. In the first nine months of the project, our efforts will be concentrated on an investigation of existing software packages. We will also be making some initial efforts to model the problem mathematically. In the second nine months, the model(s) will be refined and experimentation will be conducted. This project was funded in late September, 1989. Thus, phase one is currently four months old.

2.1 Investigation of Existing Software Packages

We began by contacting 13 vendors of COP software systems. We have had a positive response from 8 of these companies indicating an interest in participating in this project. We plan to obtain from these vendors representative software to solve the problem described in section 1.3. It will be necessary for each of these packages to be executed in a similar computing environment (e.g. a DOS-based PC platform).

We will be building a testbed data set either from an industrial setting or from an existing database. Both of these alternatives are currently being examined. The relative performance of these software packages will be investigated experimentally by running each one against the testbed data. Measures of performance will be efficiency and effectiveness. The efficiency will be measured in terms of computational time and ease of use. The effectiveness will be measured in terms of the objective function, a total weighted value of fabric cost and cutting costs.

2.2 Theoretical Analysis of Cut Order Planning

In order to effectively analyze the COP problem, it is necessary to model the problem mathematically. Other problems which seem to have bearing on the COP problem include the cutting stock problem, bin packing problems, the knapsack problem, and location-allocation problems. In addition to the mathematical basis for the problem, the modeling process will rely heavily on discussions with vendors, industrial contacts, and other AMTC personnel who are knowledgeable of the COP problem.

The COP problem is a combinatorial one, initially indicating that heuristic solution methods may be appropriate. However, the size of the problem may lend itself to exact methods. Only after the modeling process is complete can the most effective technique be determined.

Based on the problem definition given in section 1.3, an initial model has been constructed. We are currently studying this model to determine its accuracy and completeness, and as an indicator of possible solution methods. As this model is studied and refined, an ongoing review of relevant literature is being conducted as the basis for an effective solution algorithm.

The model will eventually be finalized and incorporated into a prototype software package for solving the COP problem. This prototype will be used for theoretical evaluation of the methodology and for empirical studies utilizing the testbed data.

2.3 Evaluation and Experimentation

Once the prototype system is constructed, a process of evaluation and refinement will be conducted. This process will finetune the effectiveness of the imbedded methodologies and the efficiency of the implementation. Theoretical evaluation wiil investigate such strategies as bounds on the optimal solution and worst-case analysis of heuristics. Empirical evaluation will be conducted by running the prototype against the testbed data, as will be done for the existing packages. A comparative evaluation of the prototype will be carried out based on these experiments.

Upon completion of the experimentation, conclusions and recommendations will be made. One or more of the participating vendors will be solicited to incorporate the prototype software into a commercial package so that the results of this research can be effectively assimilated into the apparel industry.

3.0 *Follow-on Work*

Because cut-order planning is the initial step in the release activity of shop floor control, it has significant impact on the performance of downstream production functions. currently COP is performed independently of subsequent assembly operations. In order to make the entire production system more efficient and more responsive to customer needs, COP must be integrated into the strategic and tactical decision making associated with the comprehensive production system.

As a result of these considerations, the COP process may be modified to explicitly consider *tradeoffs* between downstream efficiencies, cutting and fabric costs, and the impact of needed smaller lot sizes. These interactions will be captured in both COP as an activity itself as well as a better designed production planning and control system which optimizes the work release impact from the COP.

IMPROVED MARKER MAKING

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February, 1990

Sponsor: DEFENSE LOGISTICS AGENCY
Defense Electronics Supply Center
United States Department of Defense

1.0 *Introduction and Scope of Project*

1.1 Introduction

In recent years the apparel industry has focused on improving its responsiveness to the marketplace as a means of bringing the industry back onto a competitive footing with overseas manufacturers. Retail outlets are placing smaller orders for a wider variety of merchandise. This puts pressure on industry to make smaller lots more efficiently. One aspect of efficient market response is the marker making process. Most marker making systems today are far from automatic. These systems generally can be classified as computer aided design (CAD) systems, where the human operator interacts with a graphical interface to create the marker. Some systems go so far as to employ general rules, such as 'position the largest pieces first,' to invoke a degree of automation. However, the human operator actually performs most of the work. Even those systems which claim to be automatic have yet to perform significantly better than, or even as well as, a human operator.

Automatic marker making is the unattended packing of a number of "polygonal" pattern shapes into a specified width of fabric, while attempting to minimize the total length used. Unattended is meant to imply full automation, as opposed to manual or interactive techniques, using human intervention and assistance.

The marker making problem is a very difficult one. The underlying problem is a classical one from the field of operations research known as the cutting stock problem. Analysis of this problem has led researchers to two different approaches: algorithmic and heuristic.

An algorithmic approach is guaranteed to produce a mathematically optimal solution in terms of fabric utilization. However, these methods do not consider the constraints required for apparel manufacturing (nap, tilt, flip, stripe/plaid, cutting, and/or shading constraints). In addition, all of these algorithmic methods are computationally prohibitive.

Heuristic methods are designed to produce a *good* solution, but not necessarily the optimal one. Such a method must be tailored for the specific application for which it is developed in order to find solutions which meet all the requirements of the problem at hand. It is generally easier to incorporate constraints such as those listed in the previous paragraph into a heuristic method. The biggest drawback of these techniques is finding a solution that is *good enough*; specifically, a solution that is as good as, or better than a solution produced by a human operator.

1.2 Scope of the Project

The primary objective of this project is to determine the technical and economic feasibility of developing marker making systems whose performance will exceed that of existing systems, focusing on fully automatic marker making systems. In order to achieve this goal, a technical analysis of the underlying cutting stock problem will be undertaken. Information from both vendors and users will also be gathered regarding the performance and economics of existing systems. In addition, the economic issues involved in such a development will be examined. From the study of these two sides of the question, an evaluation will be made of the feasibility of developing such improved systems.

.0 *Project Activities*

2.1 Literature Review of the Cutting Stock Problem

An abundance of publications, dating from the early 1960's, related to the cutting stock problem can be found in the literature. The relevant papers have been identified and acquired. Due to the number of these papers, the process of reviewing these publications is still ongoing.

The research on this problem can be classified according to the dimension of the problem. One-dimensional cutting stock problems deal with material of one dimension which must be cut into stock pieces. Examples include pipe-cutting and board-cutting (as in the lumber industry). There are methods for solving the one-dimensional problem which may be of use in the solution of higher dimensional problems.

Two- and three-dimensional problems have also received a good deal of attention. Since the marker making problem is a two-dimensional cutting stock problem (with additional constraints), most of our attention has been focused on this literature. Unfortunately most of the research deals with "pattern pieces" which are rectangles. Since few markers are required which deal only with rectangular pattern pieces, it is obvious that the methods discussed must be adapted in some way for application to the apparel industry.

The methods described in the literature for the two-dimensional problem are either algorithmic or heuristic, as explained in the introduction. A third method which will be examined in this study is an expert system approach. It may be that some combination of these methods will hold promise for the future of automatic marker making systems.

2.2 Contact With Vendors of Marker Making Systems

In order to thoroughly understand the capabilities of current marker making systems, input has been sought from commercial vendors of these systems. We have been successful in obtaining the cooperation of four such vendors.

A survey was constructed to solicit the desired information from these marker making companies, addressing both technical and financial aspects of their systems. This survey was administered over the telephone, and we are currently compiling the results.

From this survey we were able to determine users of the various systems which we will be visiting in the near future. We will therefore obtain not only the vendors' view of these systems, but also the users' view.

2.3 Economic Analysis of the Marker Making Problem

Given the recent emphasis on nontraditional methods for economic justification of technological advances in the apparel industry, the potential costs and benefits of automated marker making are being considered in the broadest sense. The interactions of marker making with other technical and business areas of the firm are being examined along with the traditional factors associated with operator and equipment cost savings.

It must be conceded that the search for global benefits outside the traditional narrow focus has not been particularly fruitful. Some examples of such investigations would (and preliminary conclusions) include:

- It is likely that the quality of the cuts made from automatically derived markers would not be appreciably higher than current computerized manual systems, where "quality" is defined as either increased fabric utilization rates, reduced errors, or increased ability to handle complex shapes or fabrics.

- It is unlikely that training time, or learning curve effects would be appreciably lessened with more highly automated software.

- It is unlikely that automated marker making would result in an increase to effective capacity in either cutting or design.

- There would be no appreciable increase in the speed, quality, or quantity of information made available to the design, production, or costing areas of the firm.

With these rather negative preliminary conclusions regarding the economic feasibility of developing automated marker making systems, we have sought and

will be seeking input from both vendors and users of current systems as to their ideas concerning the benefits of automation in the marker making process.

The next phase of the economic assessment will gather information from firms using various levels of automation in their marker making. This information will include operator costs (including wages, fringe benefits, hiring costs, and turnover), operator productivity under a variety of scenarios, (e.g., levels of fabric complexity), equipment costs, equipment utilization. Also pursued will be the potential automated marker making has for improving the competitive position of the firm or providing additional capabilities such as aiding design for manufacturability. These data will be combined with estimated impacts from automated marker making to estimate the net present value of the investment. If intangible benefits are found to be significant, then other, nontraditional, methods of evaluation, such as the analytical hierarchy process, will be employed.

3.0 *Goals for Remainder of Project*

This project was funded in July, 1989 for a period of 12 months. In the remaining five months of the project we essentially have to complete the three tasks described above. First, the review of the cutting stock literature will be finished, discussions will be held with other researchers at Georgia Tech regarding the expert systems approach, and ideas for implementing automatic marker making will be formulated. Next, users of the various existing systems will be visited and discussions held regarding the efficiencies and inefficiencies of these systems. The vendors may be contacted again as questions arise during the evaluation of the assimilated information. Finally, the economic side of the question will be evaluated. All of this information will be utilized in making recommendations as to the feasibility of implementing improvements to existing marker making systems, up to and including the fully automatic system.

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FEBRUARY 15, 1990

CLEMSON UNIVERSITY

PRODUCTION PLANNING FOR QUICK RESPONSE

PRODUCTION PLANNING FOR QUICK RESPONSE

J. J. Kanet
J. S. Davis

Clemson University

Philadelphia PA
February 15-16, 1990

PRODUCTION PLANNING FOR QUICK RESPONSE IN THE APPAREL INDUSTRY

John J. Kanet
J. Steve Davis

Clemson University
February 14, 1990

THE PROBLEM: The specific problem addressed in this project is the discrete version of the well-known Economic Lot Scheduling problem. Our problem differs from the usual formulation found in the research literature in a number of important ways: demand for a set of different products is assumed to occur in discrete "batches" over an extended planning horizon; the setup times for the products are sequence-dependent; early shipment of orders is forbidden; batch splitting is permitted; and the penalty function is of a general convex form allowing penalties for both early and late order completion.

OBJECTIVE: The objective of our research effort is two-fold: first, to develop good heuristic algorithms for solving reasonable size instances of the problem specified above, and; second, to investigate state-of-the-art software tools for their suitability for the development of software that deploys our approach. The project's success will be measured on whether our work is accepted for presentation/publication at research conferences/journals and how suitable the prototype we develop is to the apparel industry's scheduling/planning problems as measured by end user and commercial software house reaction to our work.

METHODS: Our effort for algorithm development entails: review of existing methods for solving similar combinatorial scheduling problems; applying the more notable approaches to our particular problem; implementing the algorithm(s) on a computer; and performing comparative algorithmic studies over a well-designed set of sample problems. Performance of the algorithms will be based on such factors as run time and quality of the solution found. To test the viability of software tools we will develop a production scheduling system prototype (which also deploys our scheduling algorithms) suitable for demonstration to and evaluation by apparel manufacturers and production planning software developers.

STATUS: As of this writing the development of the algorithms is approximately 75% complete. We are currently in the stage of debugging a branch and bound algorithm which will be used in the evaluation of the various heuristic methods we will compare. The heuristic methods at this point which seem most promising include: heuristic branch-and-bound, simulated annealing, and TABU search. To date we have developed considerable experience in using "Window-based" tool kits for developing prototypes of this kind. Presently the emphasis is on organizing a good software development environment in which to work. After considerable investigation, our choice is to develop a prototype under IBM's AIX operation system, using X-windows and MOTIF standards for user interface development.

THE PROBLEM

n jobs

Job characteristics:

$r(i)$ = ready time
$p(i)$ = processing time
$s(j,i)$ = set-up time

To find a schedule defined as:

$$S = [C(1), C(2), \ldots, C(n)]$$

such that:

$$g(C(1), C(2), \ldots, C(n))$$

is minimized.

PROBLEM ASSUMPTIONS:

1. Setup times are sequence dependent
2. Early shipment of orders is forbidden
3. Batch splitting is permitted
4. Convex non-regular penalties

MOTIVATION

INTEGRATION OF FUNCTION:

Inventory Planning	Production Scheduling

INTEGRATION OF OBJECTIVES:

Holding Costs	Lateness Costs

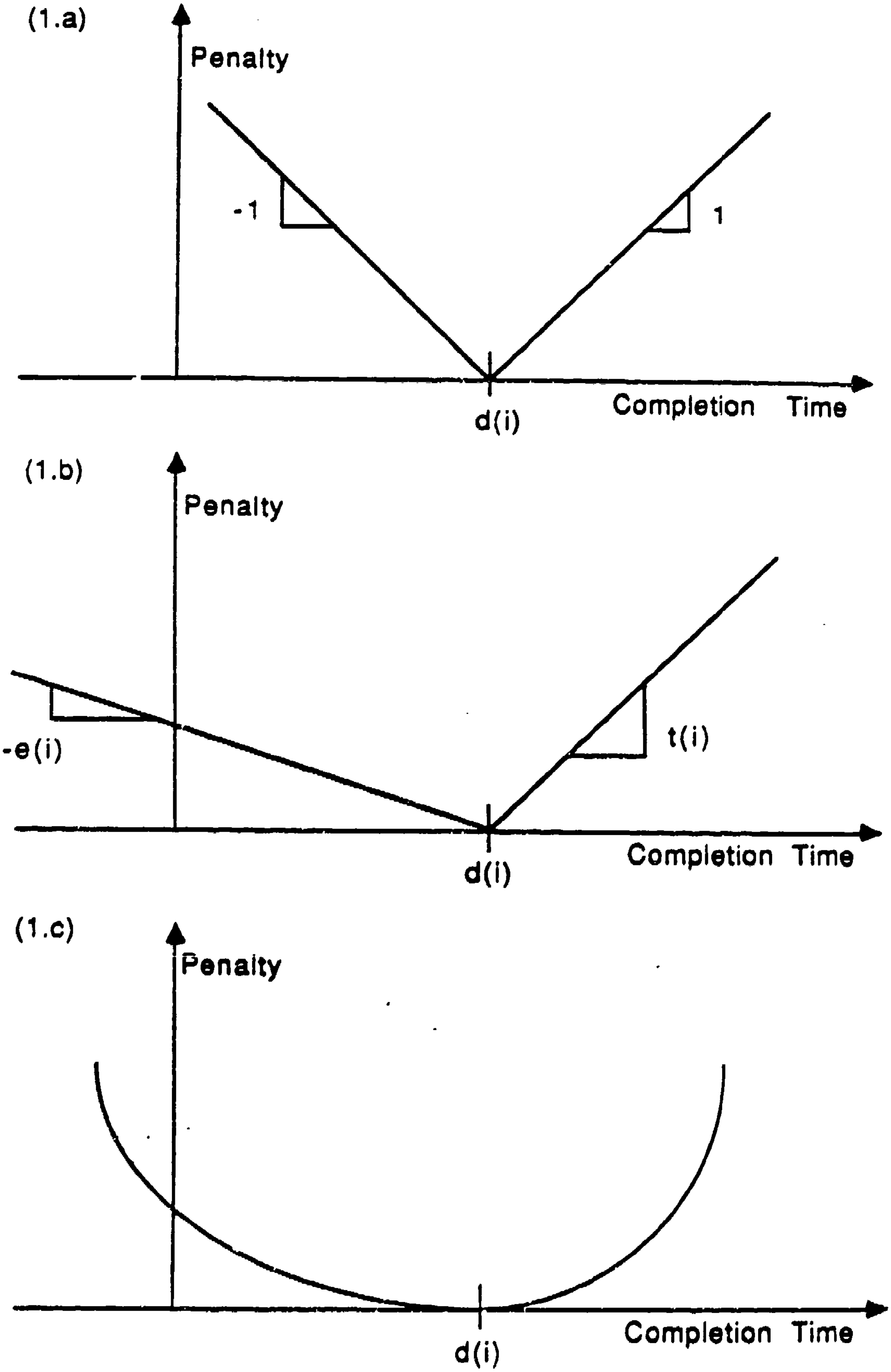


Figure 1. Examples of Different Job Penalty Functions for the ET Problem

APPAREL APPLICATIONS:

1. Vendor material planning
   (JIT delivery program)
2. Cut order planning
3. UPS planning and control
4. FMS planning and control
5. "Networked" planning systems

DLA Overall Goals:

- Balanced Program
  - Knowledge Creation
  - Technology Transfer
  - Short and Long Term Focus
- Inter-Departmental
- Multi-University
- Interface with Demo Site

Knowledge Creation:

- Long Term
  - Thesis/Tenure Work
  - Publications
  - Multi-Discipline
  - Multi-University
- Short Term
  - Specific Manufacturing Problems
  - Machine/Software Development

Technology Transfer:

- Tie in with Knowledge Creation
- University Partnerships with Machine Builders, Software Houses
- Underwrite Apparel Manufacturer's Cost of Internalizing Knowledge
- Tie in with Demo Center

RESEARCH OBJECTIVES

1. ALGORITHMS

design
development
evaluation
testing

2. PLANNING SYSTEMS

algorithm implementation
user interfacing
system prototyping
leitstands

ALGORITHMIC ISSUES:

Sequencing vs. Timetabling

Alternative Branch & Bound Design

Heuristic Procedure Development

- Good "Starting" Solutions
- Heuristic B&B
- Simulated Annealing
- TABU Search

The Clemson
"Quick Response Planner"

- a "single machine" leitstand
- full editing capability
- intelligent "re-scheduling"
- any convex objective
- sequence dependent setups
- batch sizing / lot splitting

The Clemson
Quick Response Planner

Development Environment:

Hardware:

- IBM PS/2 Model 70's (80386)

Software:

- OS/2, Presentation Manager,
  Microsoft C version 5.0

- AIX (IBM UNIX), X-WINDOWS,
  OSF's Motif
  AT&T's C++ version 2.0

STATUS (February 14, 1990)

1. ALGORITHMS

- Timetabling algorithm
- Branch and bound algorithm
- Sample problems
- Heuristics identified

. Testing and evaluation

2. PROTOTYPE

- Windows experience
- Subroutine development
- Development environment

. Implementation of algorithms
. System integration

FUTURE

IMMEDIATE:

- Develop test data
- Implement on PS/2
- Test alternative heuristics

INTERMEDIATE:

- Embed into prototype planner
- Develop and evaluate interface

LONG TERM:

- "Constraint manager"
- Networking
- Evaluation component

FEBRUARY 15, 1990

GEORGIA TECH

AUTOMATED MARKER MAKING

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

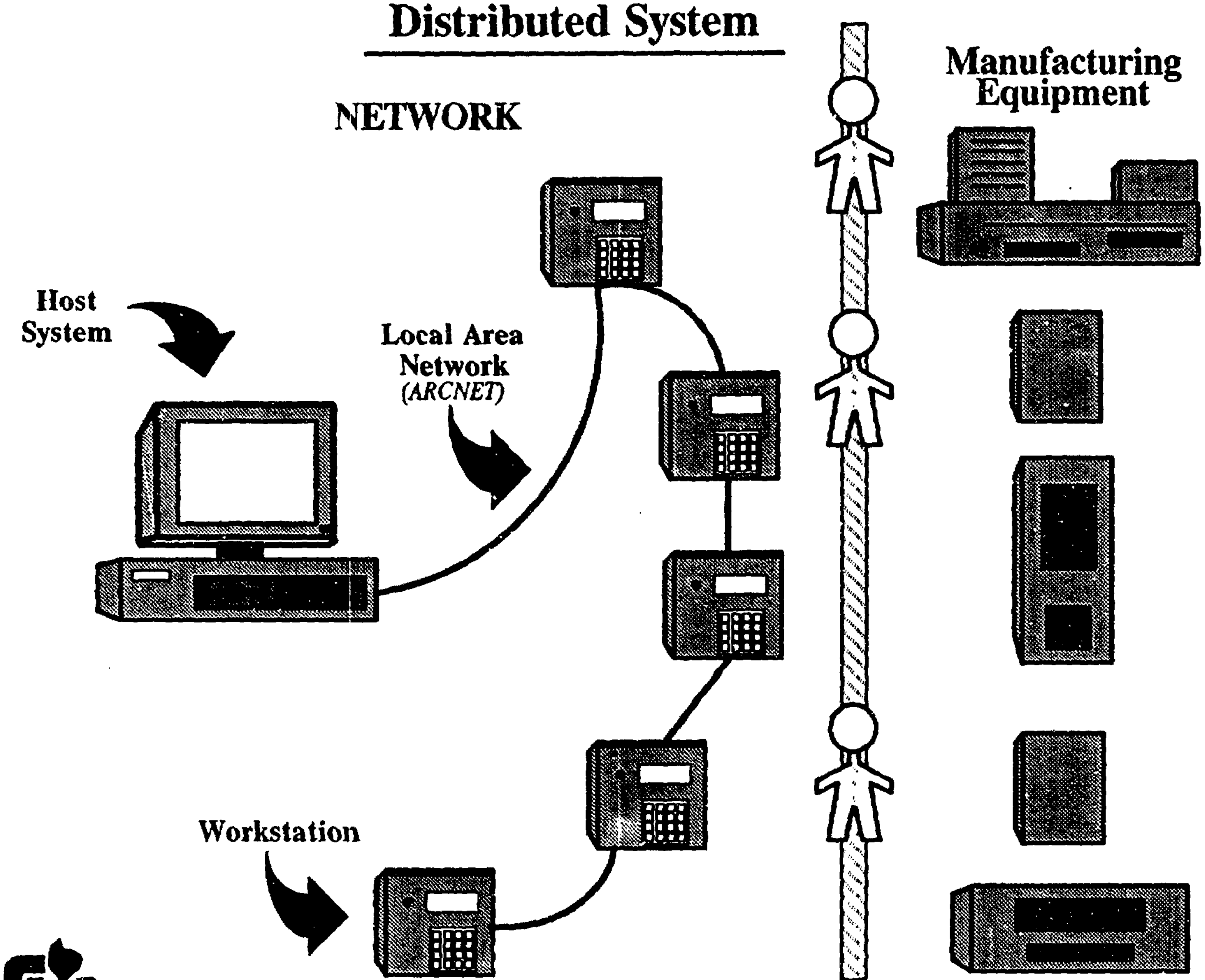
OPERATING SYSTEMS FOR DISTRIBUTED MANUFACTURING

THE DESIGN OF A COMPUTER OPERATING SYSTEM FOR DISTRIBUTED MANUFACTURING

Wayne Madison
Mike Westall
Jack Peck

Department of Computer Science
Clemson University
Clemson, S.C. 29634–1906

Distributed System



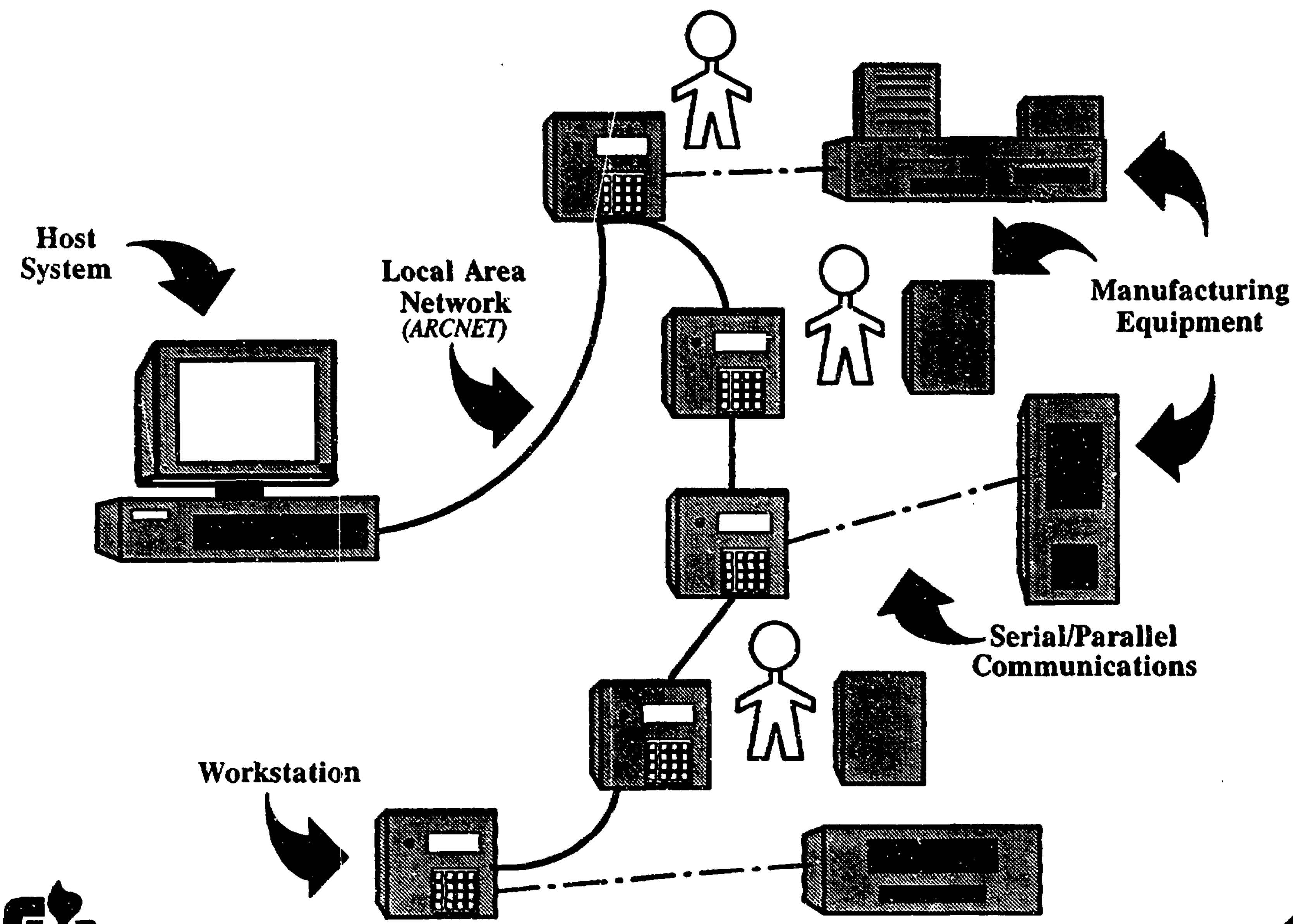
Department of Computer Science
CLEMSON UNIVERSITY

OBJECTIVES

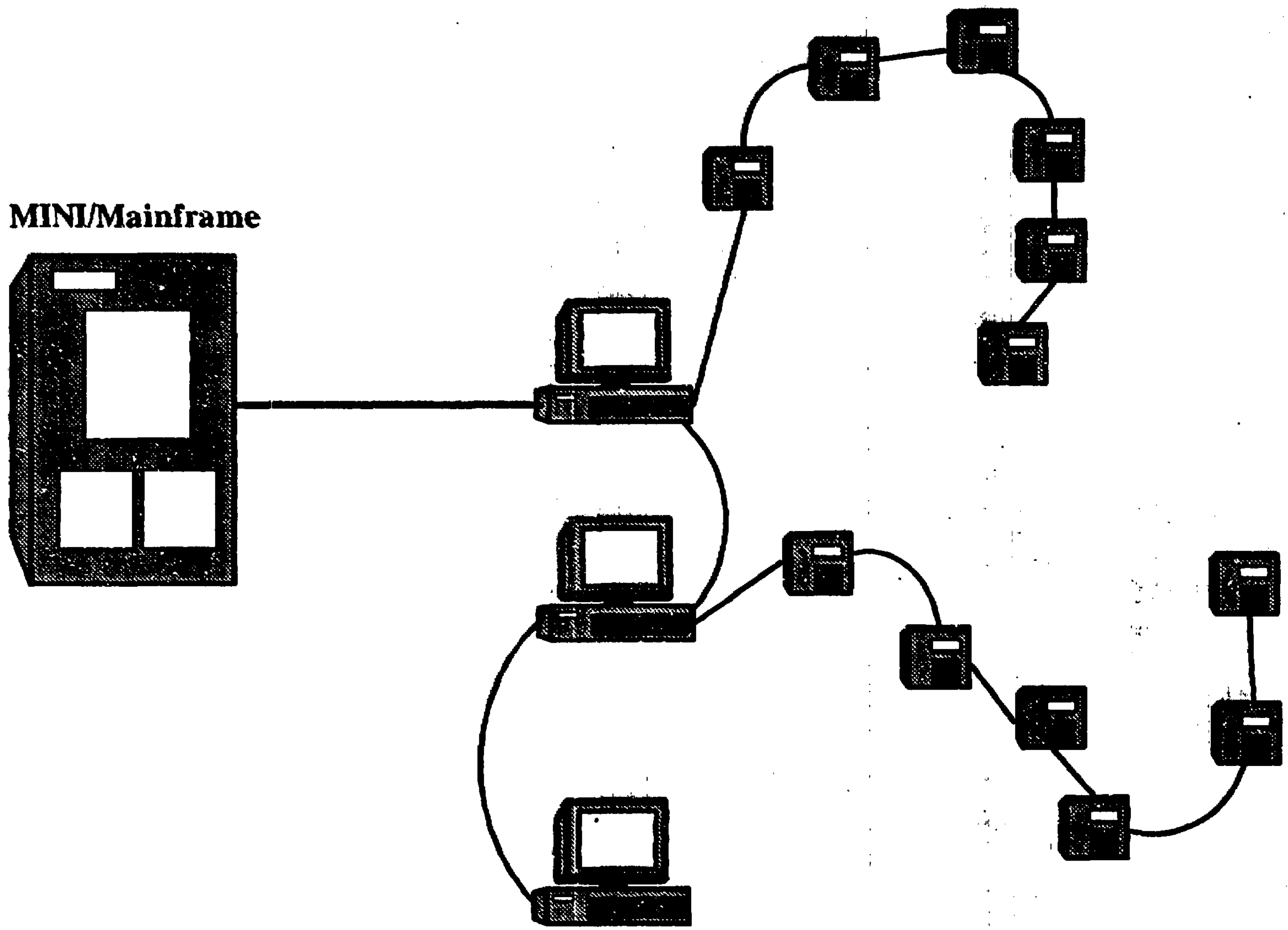
Develop a Distributed System for Apparel Manufacturing that provides for:

- "Real–time" collection of data for processing by a central host
- "Real–time" control of equipment
- Individualized capability at different workstations in the system
- Dynamic reconfiguration of workstations to adapt to changing requirements

Distributed System



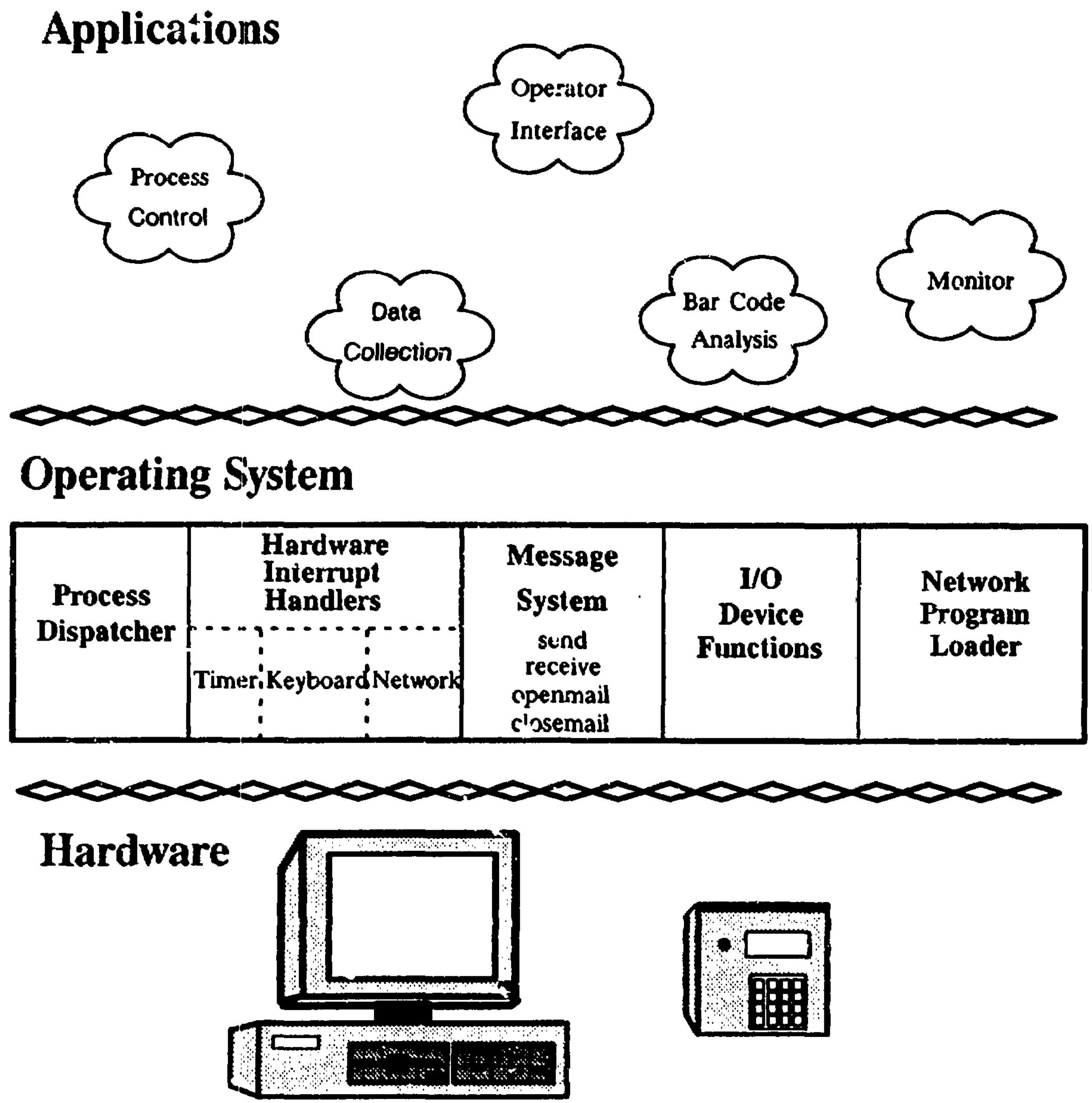
Distributed System



OPERATING SYSTEM DESIGN GOALS

- Multi-tasking
- Portable
    - ○ Readily ported between different architectures
    - ○ Common to both host and workstation
- Small
    - Compatable with low-cost hosts and workstations
- Support for distributed processing

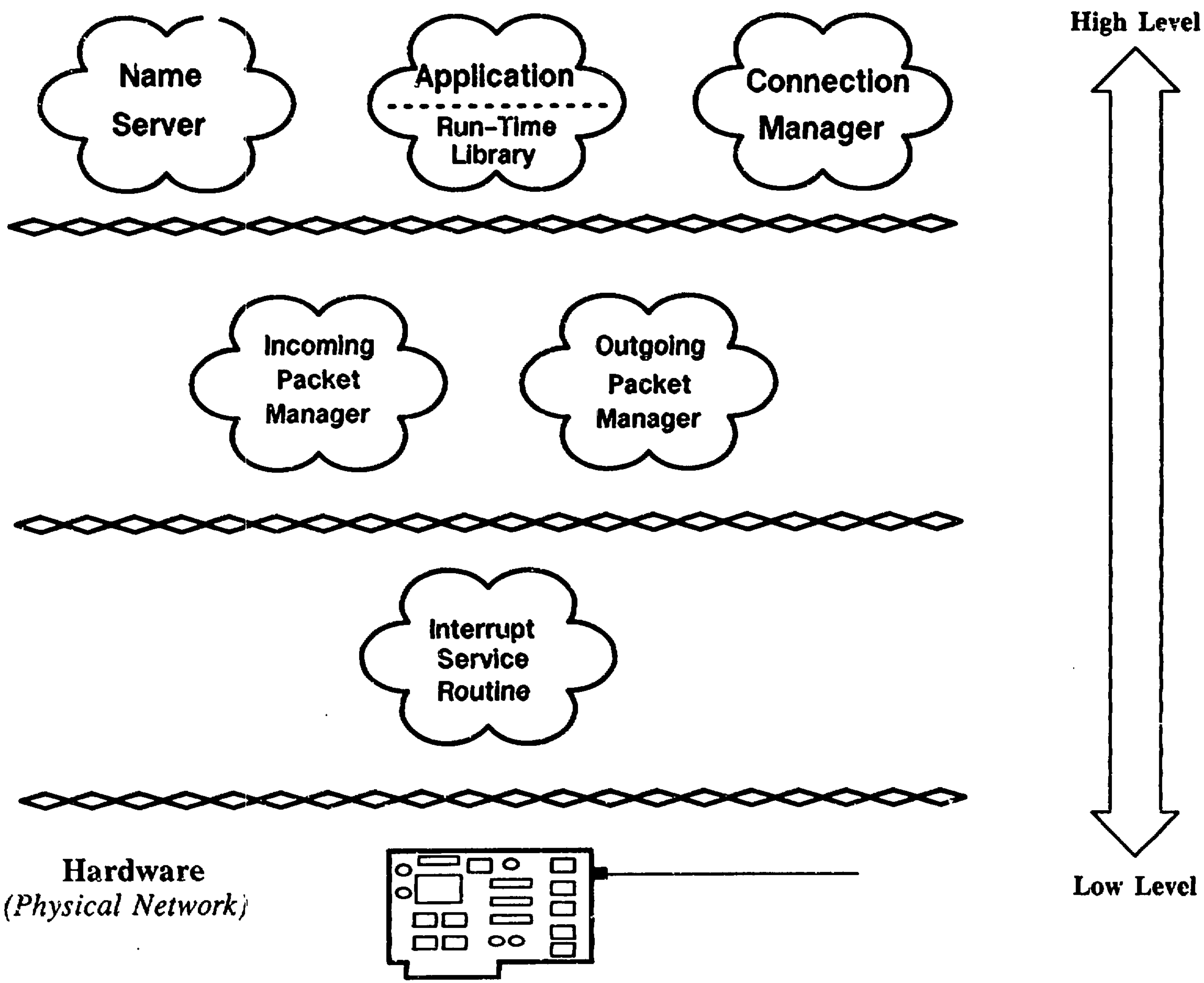
OPERATING SYSTEM DESIGN



NETWORK DESIGN GOALS

- High Speed Data Communications (LAN)
- Design Independent of Physical Network
- Process Oriented with Message Passing
- Connection and Connectionless Based Operations
- Name Server

NETWORK DESIGN



RELATION TO ISO LAYERED NETWORK MODEL

ISO MODEL	Network Design
Application	Application
Presentation	Null
Session	Connection Mgr. Name Server
Transport	Run Time Library
Network	Null
Logical Link Level	IPM/OPM ISR
Medium Access Control	ARCNET Adapter
Physical	ARCNET

Network Output Message Processing

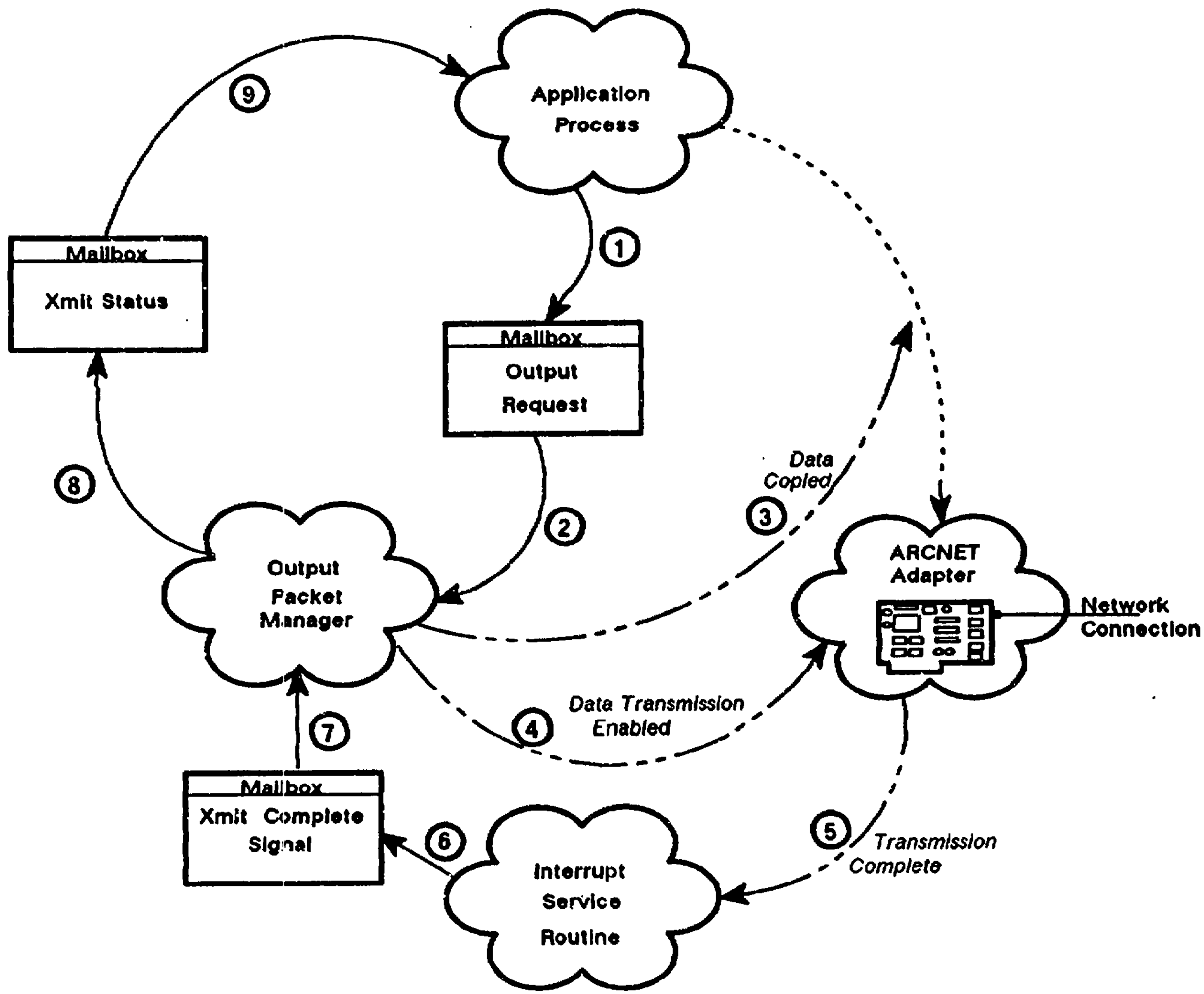


Figure 3

Network Input Message Processing

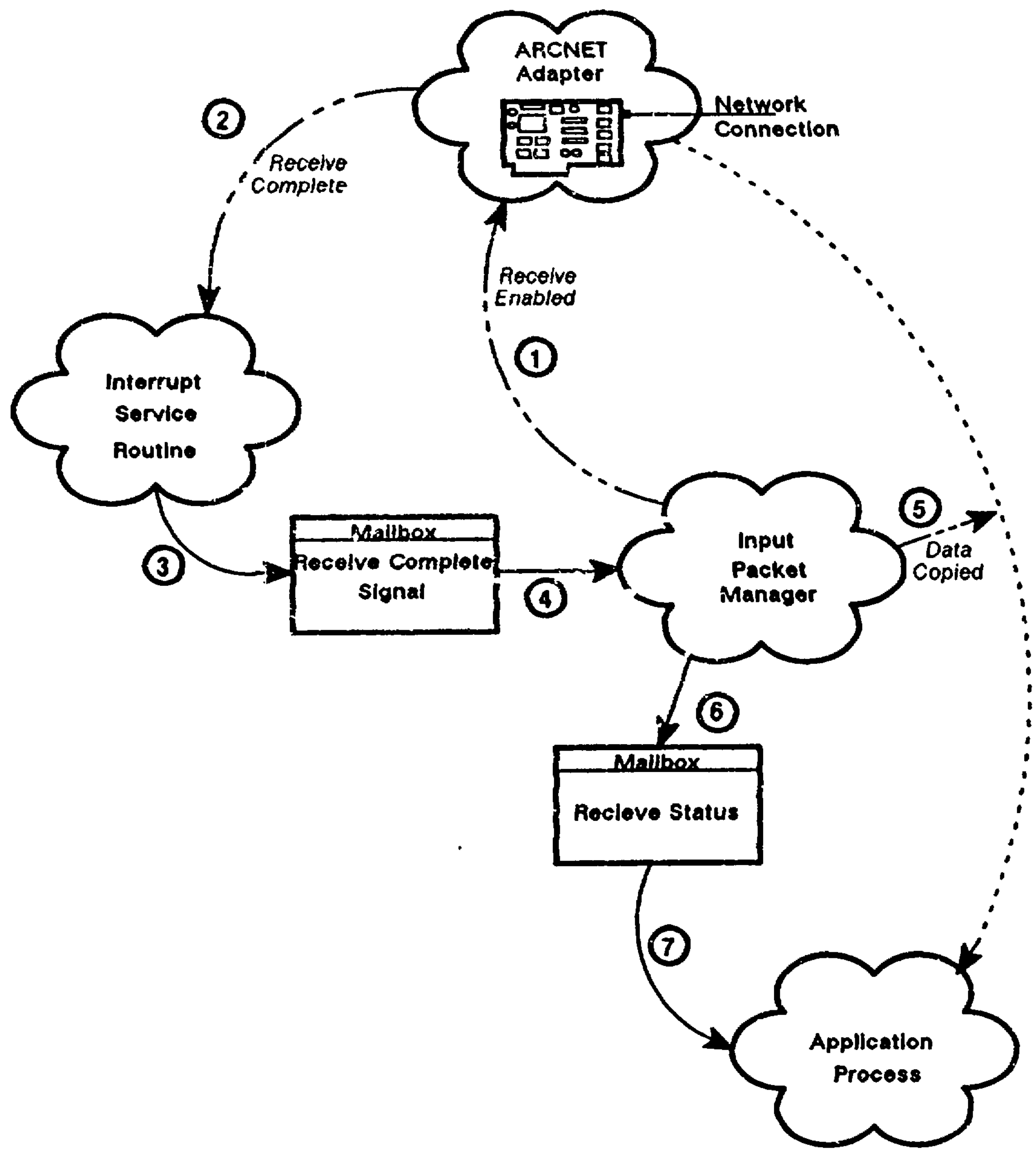


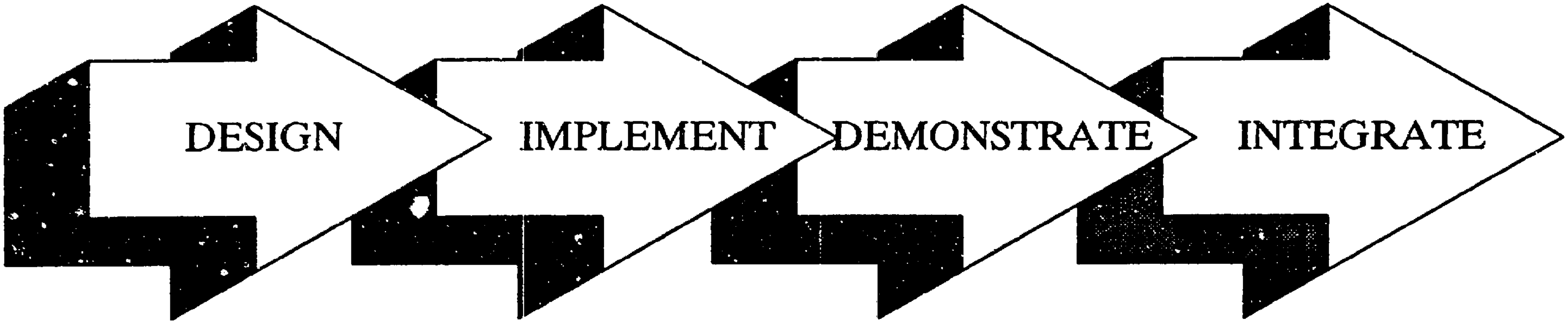
Figure 2

NAME SERVER DESIGN

- Host Based (Centralized)
- Symbolic names resolved to node number, port number.
- Default file loaded at system initilization
- Functions:
  - Register -- add an entry
  - Unregister -- delete an entry
  - Resolve -- return (node,port)

DEMONSTRATION EFFORT

- Demonstrate concept on actual hardware



EQUIPMENT FOR DEMONSTRATION EFFORT

- **Host System -- IBM PC**
  - 640 k RAM
  - 20 meg disk
  - ARCNET
- **Workstation -- NetPlus (Hand Held Products)**
  - Motorola 68HC11 Processor
  - 64 k RAM/ROM
  - ARCNET
  - Keypad
  - LCD Display
  - Bar Code Reader/Wand
  - LED
  - Audible Alarm

NETWORK ENVIRONMENT

- **ARCNET Hardware -- token bus architecture**
  ***but* simpler, slower and cheaper than**
  IEEE 802.4 standard

  2.5 megabit/second data rate
  4 on–board 512 byte data buffers
  4 miles maximum length
  255 maximum stations
  Error checking and acknowledgement
  Automatic free buffer enquiry

STATUS

- Design effort complete
- OS Complete on PC
- OS Complete on NetPlus Workstation
- Network software complete on PC
- Network software under test on NetPlus Workstation
- Demonstration in May

FUTURE DIRECTIONS

- Port OS to other platforms
- Design and prototype "appropriate" workstation
- Port Network Software to other OS's (e.g. OS/2)
- Interface with other, existing systems
- Interface with various textile equipment
- Integrate system into actual manufacturing environment

FEBRUARY 15, 1990

UNIVERSITY OF SOUTHWESTERN LOUISIANA

INTERFACE STANDARDS

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

GEORGIA TECH

ARCHITECTURE OF APPAREL MANUFACTURING

DESIGN AND DEVELOPMENT OF AN ARCHITECTURE FOR APPAREL MANUFACTURING

Research Sponsored by:

U.S. Defense Logistics Agency

(DLA900-87-D-0018 CLIN 0007)

Principal Investigator: Dr. Sundaresan Jayaraman
Graduate Research Assistant: Rajeev Malhotra

Georgia Tech Project #: E-27-628

Georgia Institute of Technology
School of Textile Engineering
Atlanta, GA 30332

(404) 894-2490

July 1988 - January 1990

SJ-TR-ARCH-FEB-15-90

Overview

* Need for the Research

* Benefits from this Research

* Research Objectives

* Tasks Accomplished

* Further Plans

* Acknowledgements

Computer-Integrated Manufacturing (CIM)

* Competitiveness

  Global Economy

  Imports

* Apparel Industry:

  Productivity, Market Share

* CIM / Automation: Keys to Success

* Understand

  What is Happening?

  How it is Happening?

  Why it is Happening?

Apparel Manufacturing Architecture

(AMA)

* Function
* Information
* Dynamics

Benefits from Architectural Approach

* Improved Organizational Awareness

* Communication Vehicle for Organization

* Basis for Cost-Benefit Analysis

* Defining STANDARDS for Equipment and Information Exchange

  (APDES)

* The LOCKHEED Experience (!!!)

Lockheed Learns Costly Lesson in System Design

By Robert L. Scheier

Information systems are only as good as the information put into them.

That point was driven home last week as officials at Lockheed Aeronautical Systems Corp. said the failure to include critical data in an executive information system (EIS) prevented the system from spotting a problem that could cost the company $300 million.

What turned out to be the critical information was the weight of Lockheed's new P-7 antisubmarine aircraft, which was rising beyond expectations.

Officials at the Burbank, Calif., firm said they failed to include the weight data as they were inputting information about the P-7 into the EIS.

"We were two or three steps away from reaching the piece that in this case was critical," said George Houdeshel, who was systems manager for the EIS before retiring in December.

See LOCKHEED Page 6

Jan 31, 1990

Importance of "Architecture"!

Lockheed \ *Asking the Right EIS the Wrong Questions*

Continued from Page 1

"Only [some] pieces of the puzzle were in the automated system," added Bill Bernstein, a Lockheed vice president and program manager for the P-7.

The EIS didn't catch the detail. Instead, Bernstein found it on printouts generated by a separate computer system.

It was only then that Lockheed officials discovered why the weight was rising: Designers had originally counted on reusing certain parts from an earlier aircraft, the P-3. But the inclusion of these parts would have prevented the P-7 from meeting the Navy's structural and performance requirements.

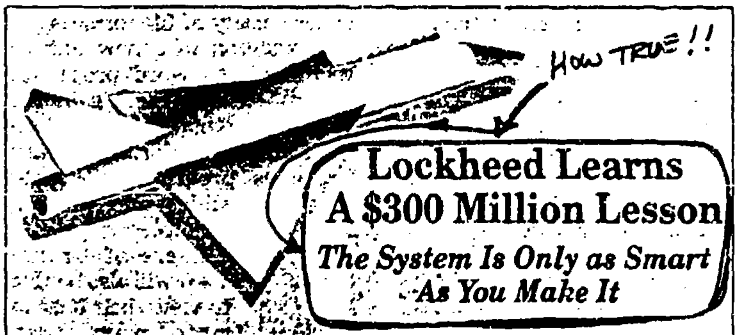
As a result, Lockheed was forced to design new parts, which unexpectedly drove up the weight of the aircraft.

The mistake, disclosed last fall by Lockheed officials, could cost as much as $300 million and may cause the firm to report a net loss for the year.

Houdeshel and Bernstein declined to say exactly why the weight information was not included earlier.

Decisions about what was to be included in the EIS involved both executives and information-systems staff, according to Houdeshel. However, such decisions are complicated by the fact that the potentially critical information is not always obvious.

"I wouldn't have thought the weight problem would have been critical, but it happened to be in this case," he said.



Lockheed believed its executive information system tracked everything, until a critical error occurred. A seemingly small detail — the weight of the P-7 aircraft it was building for the Navy — was never programmed into the EIS by the system's designers. The omission cost the company millions.

Kelly Hale

Lockheed's 12-year-old EIS, which was developed in-house, and runs on a Digital Equipment Corp. VAX, and is accessed through IBM XTs or PS/2 Model 50s.

Executives can use it to call up stick drawings of C-130 transports, for example, showing their progress down the assembly line, with wings and engines appearing as the planes near completion.

They can also scroll through instant updates on sales negotiations with foreign governments—including the names of key contacts, whether the buyers have financing and the probability of closing the sale.

"Lockheed was a real pioneer when it came to EIS," said David Friend, president of Pilot Executive Software Inc., an EIS vendor in Boston.

"We don't know what kind of disasters the EIS has averted, because you won't read about them in The Wall Street Journal. But I bet there's plenty of them, because people at that company speak very highly of that system."

Many EISs "are limited to the tracking and control of various financial and production numbers," he said. But what really should be included in an EIS are "issues," he explained, such as details of Lockheed's P-7 contract with the Navy.

"It might be weather information for oil-drilling companies," Friend said. "These are things executives deal in, but they're just not naturally captured in the system." ∎

Research Objectives

* Design and Develop AMA

* A GENERIC Architecture

* Software Models: Usable (PC/AT Class)

Approach

* Three Phases

  July 1988 - June 1990

* Function

* Information

* Dynamics

Tasks Accomplished

* Modeling Methodology
* Establish Evaluation Criteria
* IDEF / STRADIS / Tools
* IDEF Selection
* Industry Partner for Collaboration
  Oxford Slacks, Monroe, GA

Function Model

* Interviews with Managers

* Written Reports

* Software Implementation

  (Wizdom's IDEFine)

* Decompose Function to Desired Degree of Detail (Cell Modeling Technique)

  Inputs

  Controls

  Outputs

  Mechanisms

Model: Enterprise

* Context:

  Operate an Apparel Enterprise

* Purpose:

  Develop Functional Spec for a CIM System in an Apparel Enterprise

* Viewpoint:
  Managers Responsible for Day-to-Day Operations of the Enterprise

* AS IS Model

* TO BE Model

* Glossary of Terms

* CIM/COM Members

    Model

    Levi Strauss

* Videotape of Function Model

MODEL INDEX FILE OF: enterprise

(RMX016)	A1 Develop Garment for Manufacture
(RMX060)	A11 Market Product
(RMX061)	A111 Create New Styles & Concepts
	A1111 Study Fashion Trends
	A1112 Create New Styles
	A1113 Develop Styles Based on Customer's Ideas
(RMX062)	A112 Sell New Concepts & Styles to Customer
	A1121 Make Sales Contact with the Customer
	A1122 Determine Customer's Requirements
	A1123 Get Sample Information from the Customer
(RMX063)	A113 Work Out Details of Prospective Sale
	A1131 Prepare Quotations for the Customer
	A1132 Request Samples From Sample Department
	A1133 Procure Fabric for Samples
(RMX017)	A12 Develop Product Detail
	A121 Create Garment Model
	A122 Determine Manufacturability
(RMX018)	A123 Estimate Manufacturing Costs
	A1231 Estimate Operations Cost
	A1232 Estimate Material Cost
	A1233 Estimate Material Requirement
(RMX019)	A13 Provide Sample Garments
	A131 Control Sample Production
(RMX020)	A132 Make & Grade Pattern
	A1321 Verify Fit Details
(RMX021)	A1322 Make Pattern
	A13221 Select Base Pattern
	A13222 Modify Base Pattern Parts
	A13223 Generate New Pattern
	A13224 Assign Pattern & Run Numbers
	A1323 Make Grade Rules
(RMX022)	A1324 Make Marker
	A13241 Digitize Pattern
	A13242 Enter Grade Rules Into Computer
	A13243 Grade Pattern & Lay the Marker Out
	A13244 Plot the Marker
(RMX023)	A133 Produce Sample Garments
	A1331 Plan Cutting & Sewing Operations
	A1332 Cut Fabric
	A1333 Sew Sample Garment
	A134 Test Sample Garments

USED AT:	AUTHOR : Rajeev Malhotra DATE: 16/11/88	X	WORKING	READER DATE	CONTEXT:
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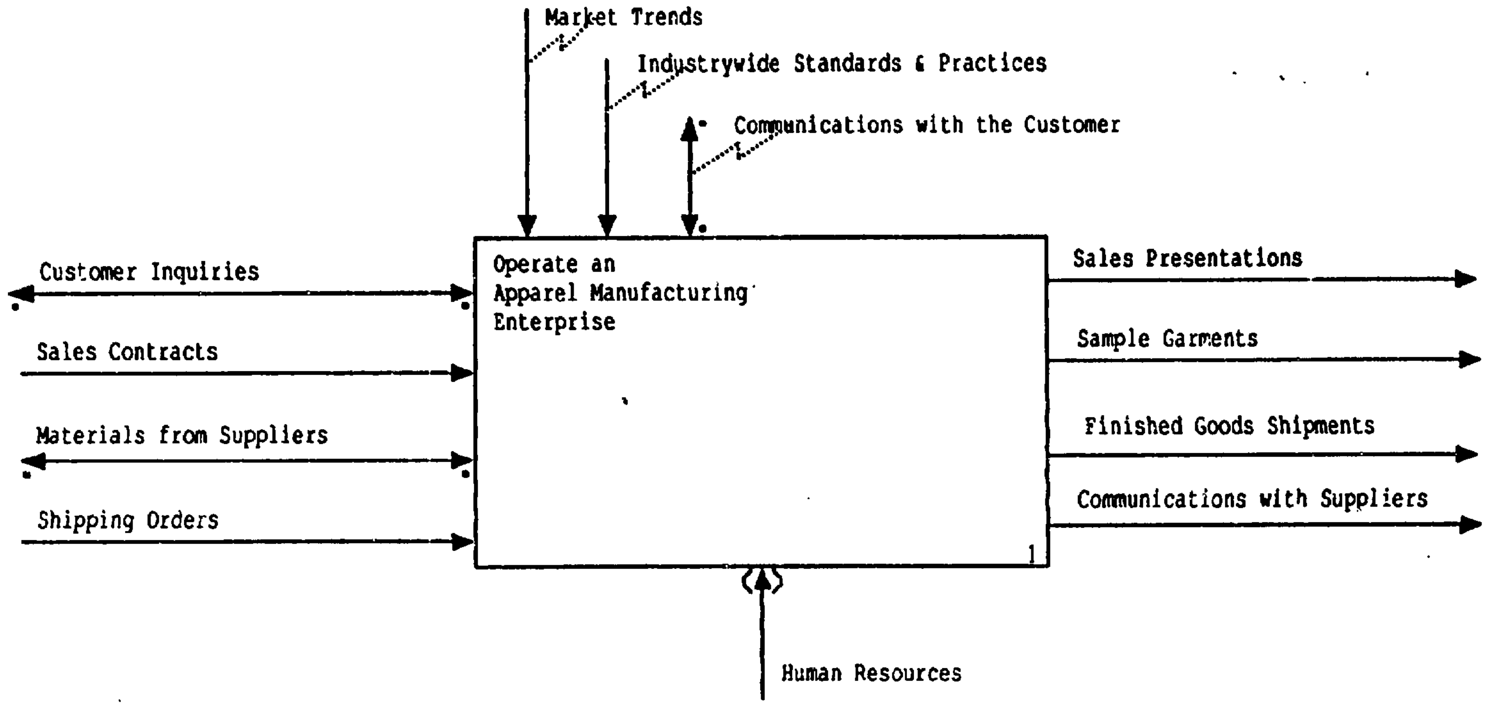
	COMPANY: Georgia Institute of Technology		RECOMMENDED		
	NOTES : 1 2 3 4 5 6 7 8 9		PUBLICATION		



1 VIEWPOINT: Managers responsible for day-to-day operations of the enterprise.

2 PURPOSE: Develop the functional specification for a CIM system for an apparel manufacturing enterprise.

NODE:	TITLE:	NUMBER:
enterprise/A-0	Operate an Apparel Manufacturing Enterprise	RMX1

USED AT:	AUTHOR : Rajeev Malhotra	DATE: 16/11/88	X	WORKING	READER	DATE	CONTEXT: RMX1
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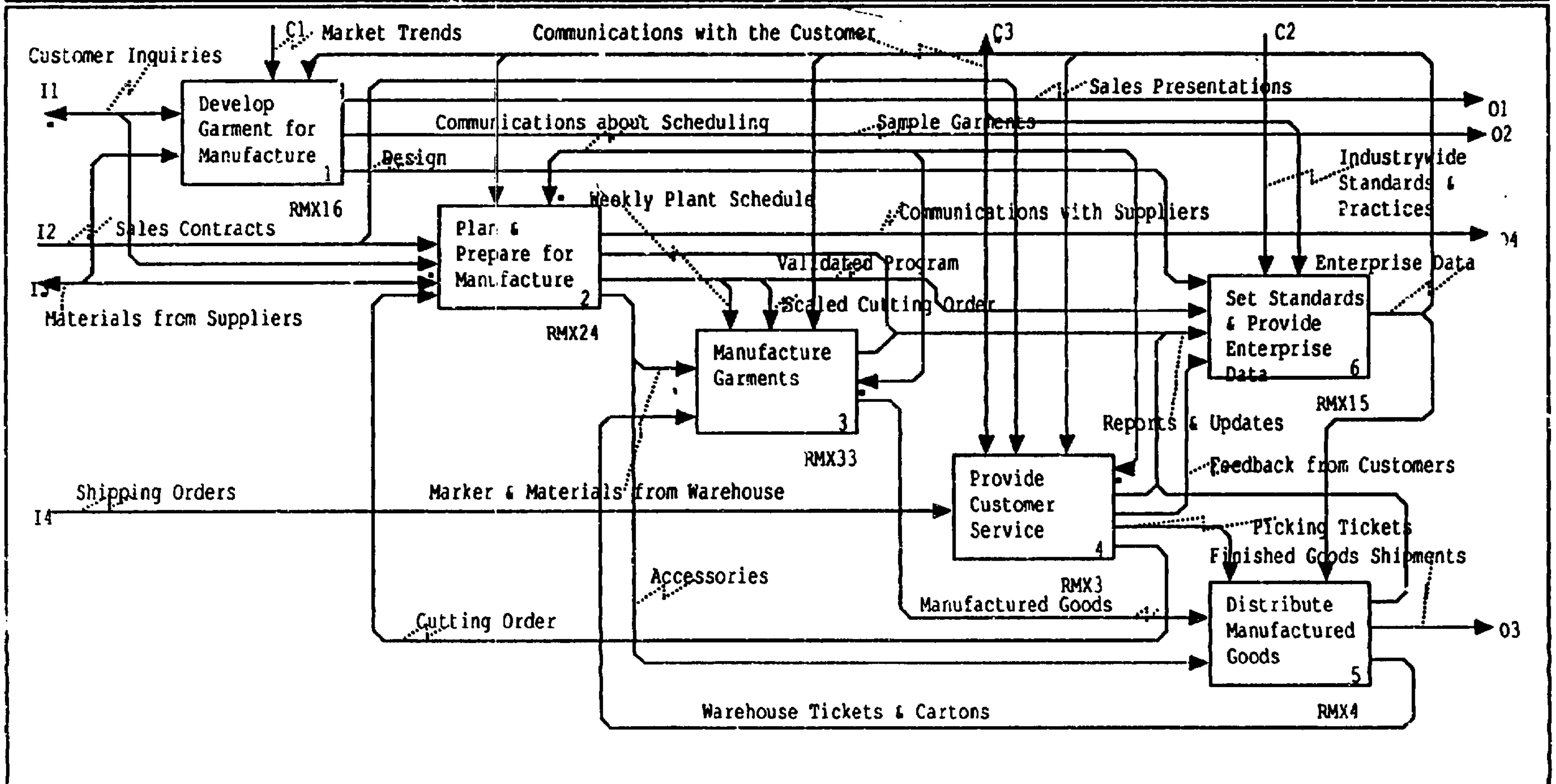
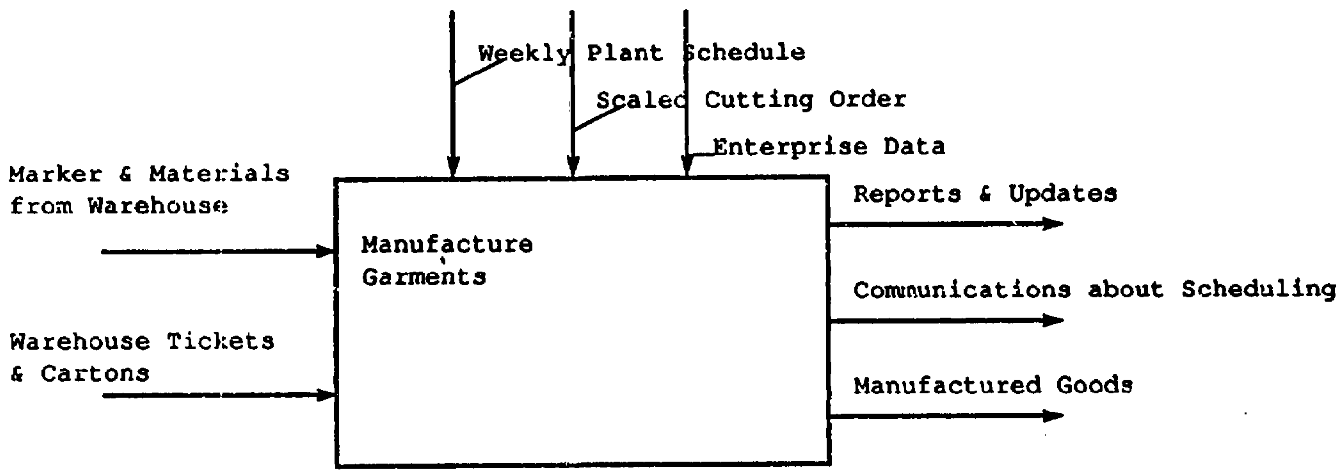
	COMPANY: Georgia Institute of Technology			RECOMMENDED			
	NOTES : 1 2 3 4 5 6 7 8 9			PUBLICATION			A-0



NODE:	TITLE:	NUMBER:
enterprise/A0	Operate an Apparel Manufacturing Enterprise	RMX2

A3

Manufacture Garments



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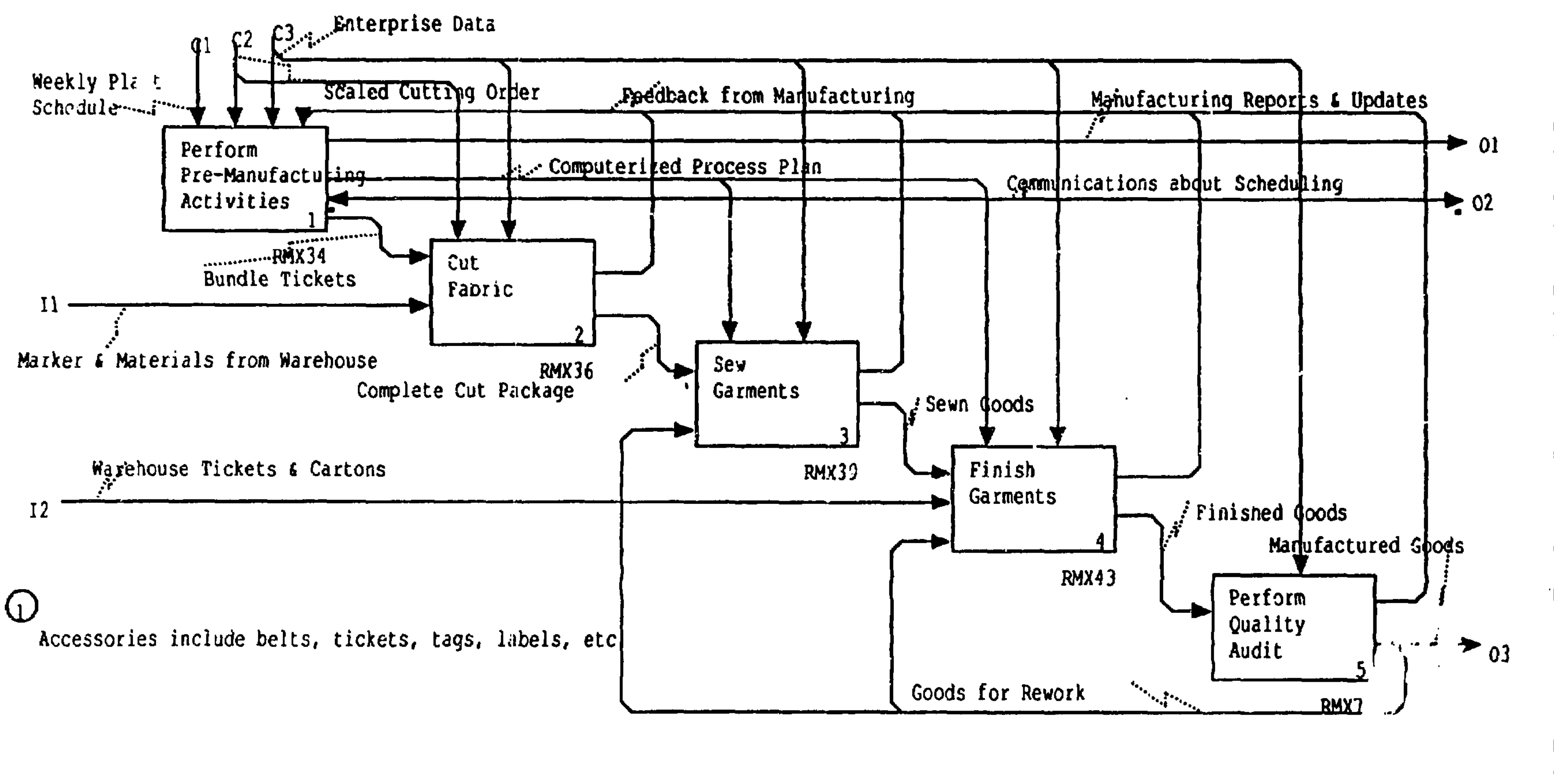

NODE:	TITLE:	NUMBER:
enterprise/A3	Manufacture Garments	RMX33

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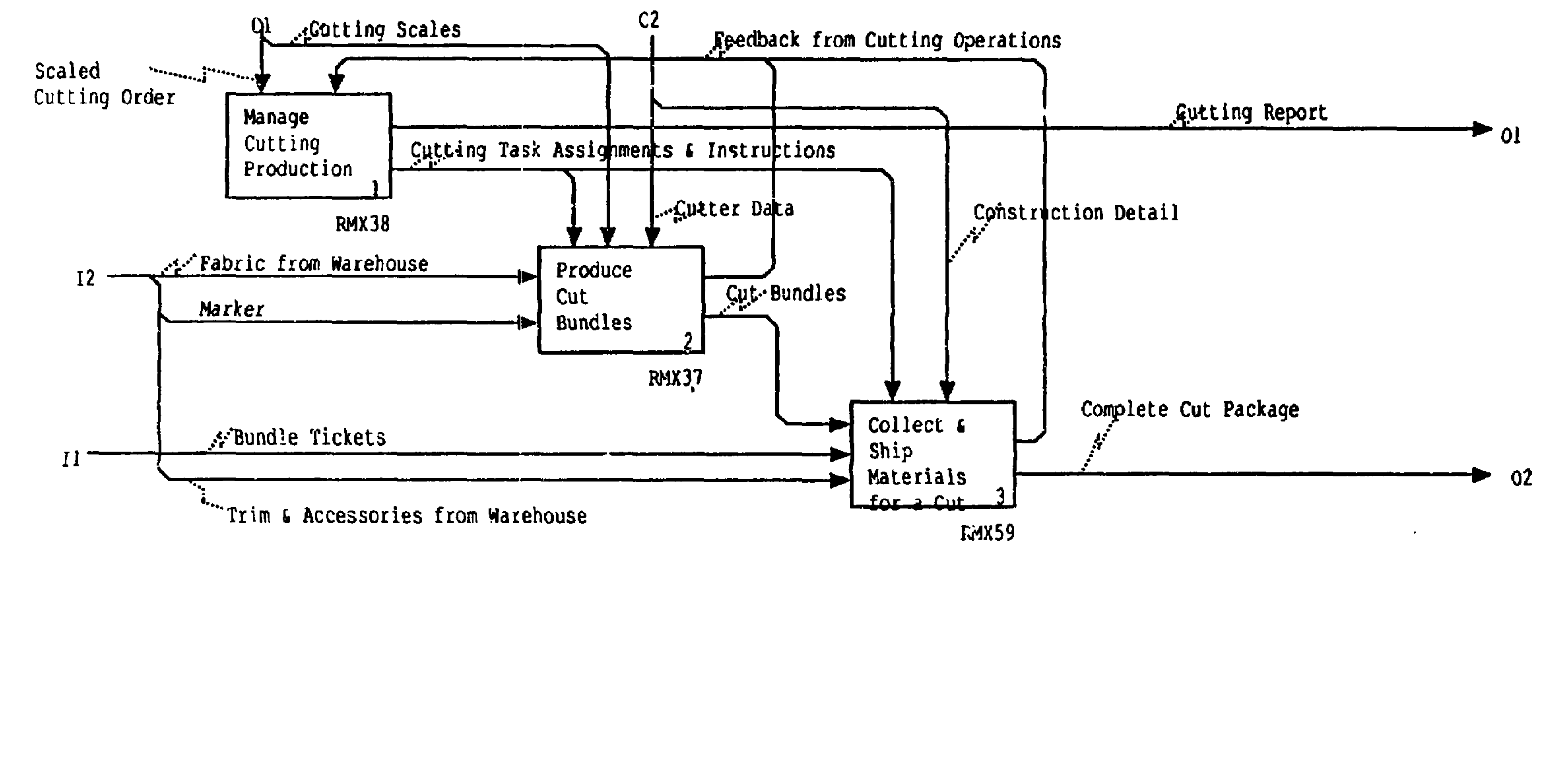

NODE: enterprise/A32	TITLE: Cut Fabric	NUMBER: RMX36

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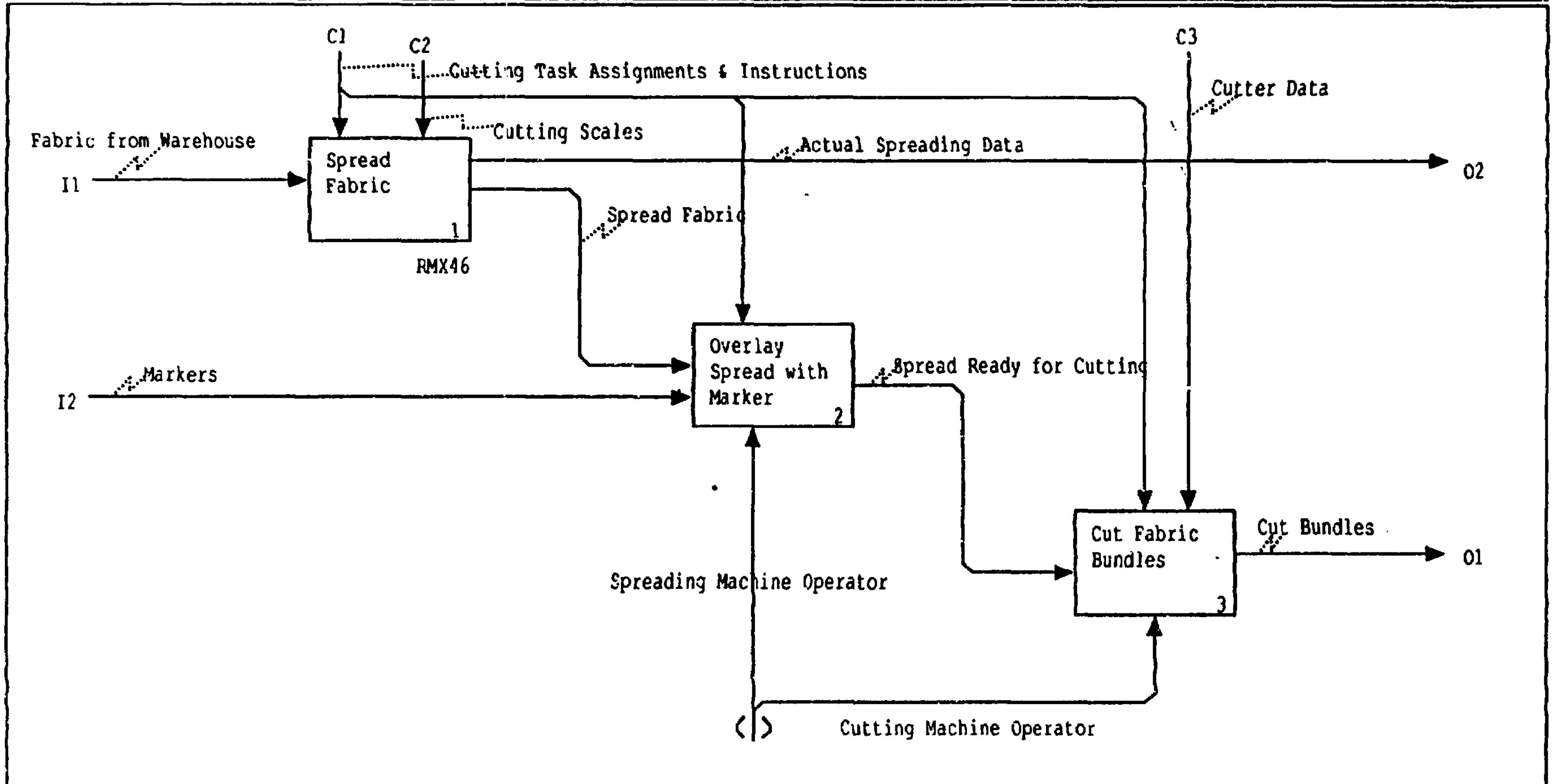
				RECOMMENDED			
				PUBLICATION			A32



NODE:	TITLE:	NUMBER:
enterprise/A322	*Produce Cut Bundles*	RMX37

USED AT:	AUTHOR : Rajeev Malhotra DATE: 10/11/88 PROJECT: enterprise REV.: 22/3/89 COMPANY: Georgia Institute of Technology NOTES : 1 2 3 4 5 6 7 8 9	X	WORKING	READER	DATE	CONTEXT: RMX37
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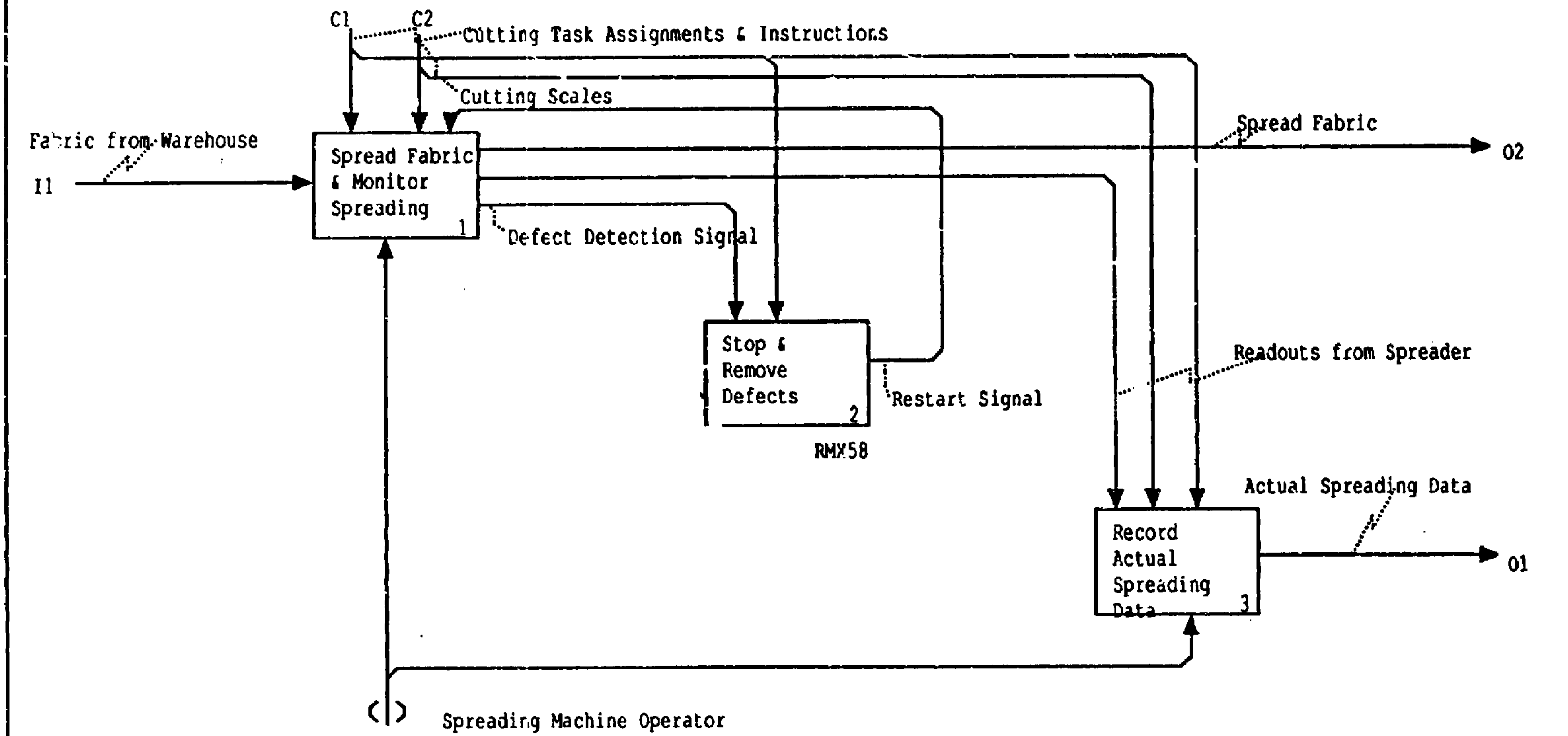
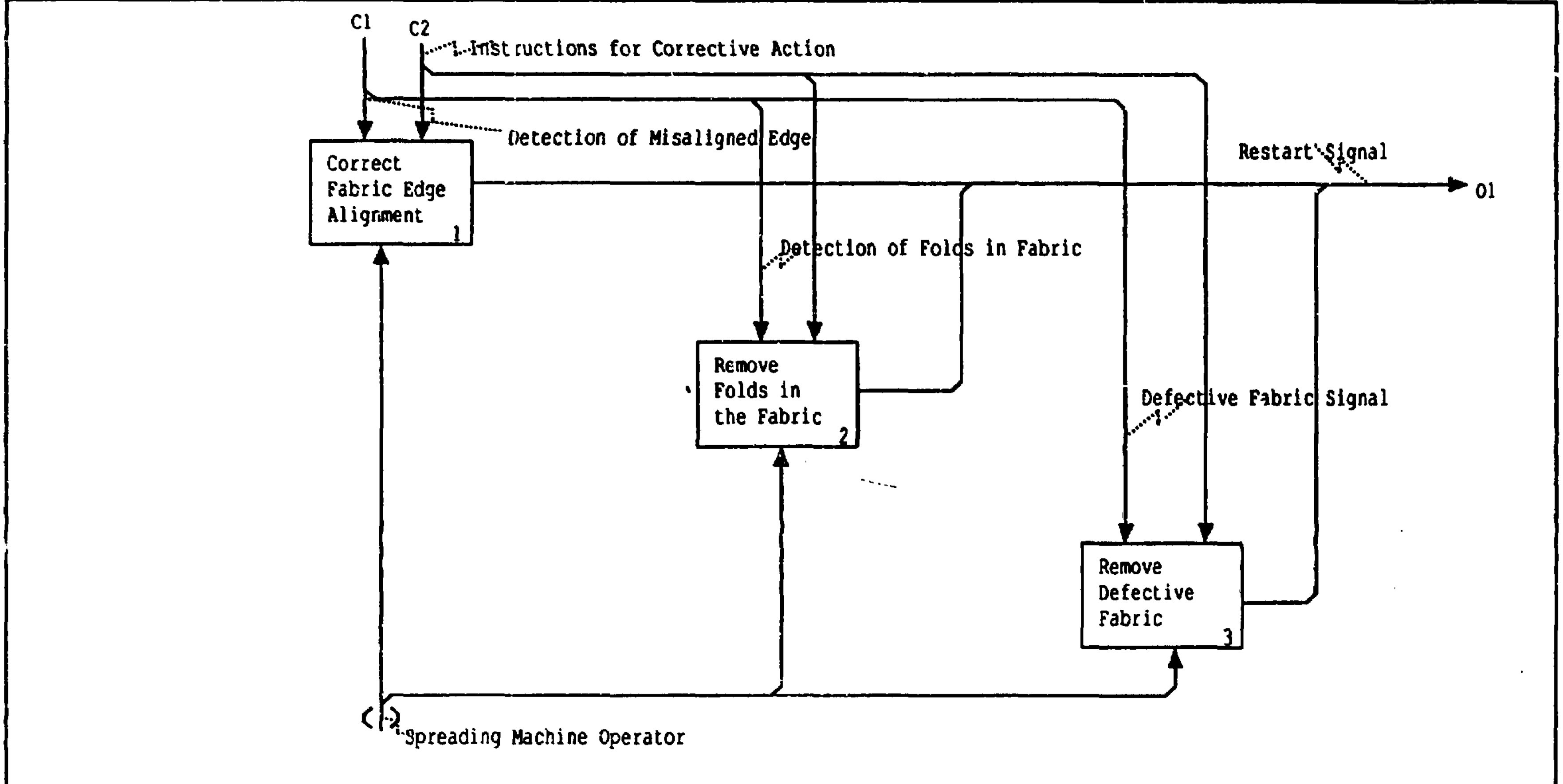
			PUBLICATION			A322



NODE: enterprise/A3221	TITLE: Spread Fabric	NUMBER: RMX46

USED AT:	AUTHOR : Rajeev Malhotra DATE: 21/2/89 PROJECT: enterprise REV.: 22/3/89 COMPANY: Georgia Institute of Technology NOTES : 1 2 3 4 5 6 7 8 9	X WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT: RMX46 A3221



NODE:	TITLE:	NUMBER:
enterprise/A32212	Stop & Remove Defects	RMX58

Decision on Manufacturability
Decision about the capability of the enterprise to manufacture the style under consideration.

Defect Detection Signal
Signal from the spreading machine indicating defect in fabric or in spreading.

Defective Fabric Signal
Spreading machine signal to indicate detection of defective fabric segment.

Design
The construction detail, the pattern and the grade tables for a garment style.

Design Concept
The design or the style of the garment in its raw form before it is developed into a complete design. This may be a sketch, a photograph or a sample garment from some external source.

Detection of Folds in Fabric
Detection of folds in the fabric being spread for cutting.

Detection of Misaligned Edge
Detection of the fabric layers not falling over each other during spreading.

Distribution Personnel
Employees of the finished goods distribution department.

Engineering Personnel
Employees of the industrial engineering department of the enterprise. The department is responsible for setting the engineering standards, writing job description and determining the job grades for each operation performed in manufacturing.

Enterprise Data
The data maintained by various entities in the enterprise to aid them in performing their functions.

Fabric Color File
A record file containing identification for each fabric color used by the enterprise.

Fabric Inspection Samples
Samples of the received fabric taken for fabric inspection.

Fabric Specification
Description of the fabric to be used for manufacture of garments of a particular style. The samples are usually made from the fabric that would be used later in production.

Fabric Specifications & Swatches
Pieces of fabric to be used for the order, its description and its likely supplier.

Information Model

* Function Model as the Basis

* Information Entities

* Entity Relationships

* Entity Attributes

* Attributes

  Primary / Non-key / Foreign

* Glossary / Entity Descriptions

USED AT:	AUTHOR : Rajeev Malhotra PROJECT: enterprise COMPANY: GEORGIA TECH. NOTES : 1 2 3 4 5 6 7 8 9	DATE: 18/7/89 REV.: 2/10/89	X	WORKING	READER	DATE	CONTEXT:
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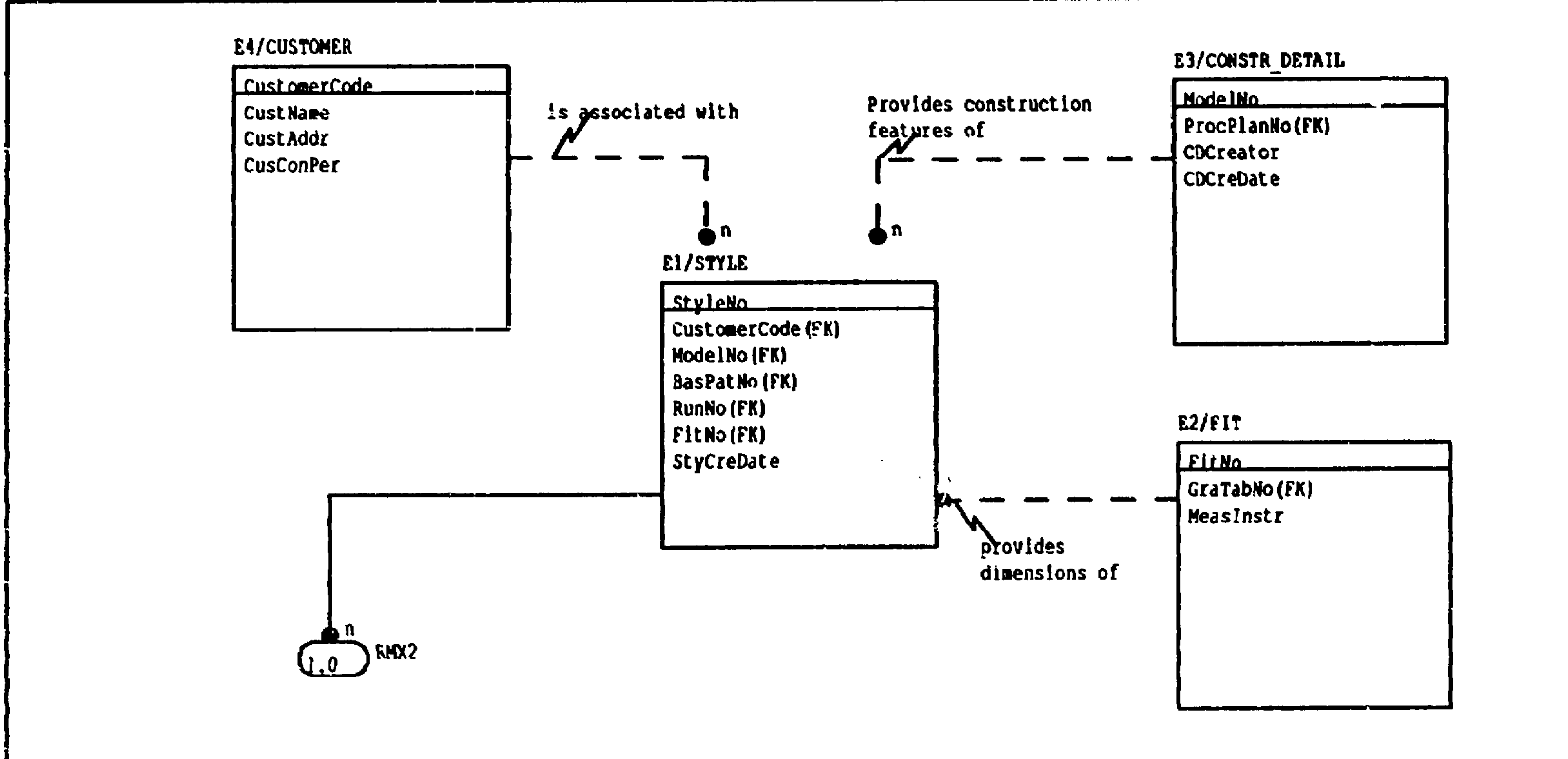
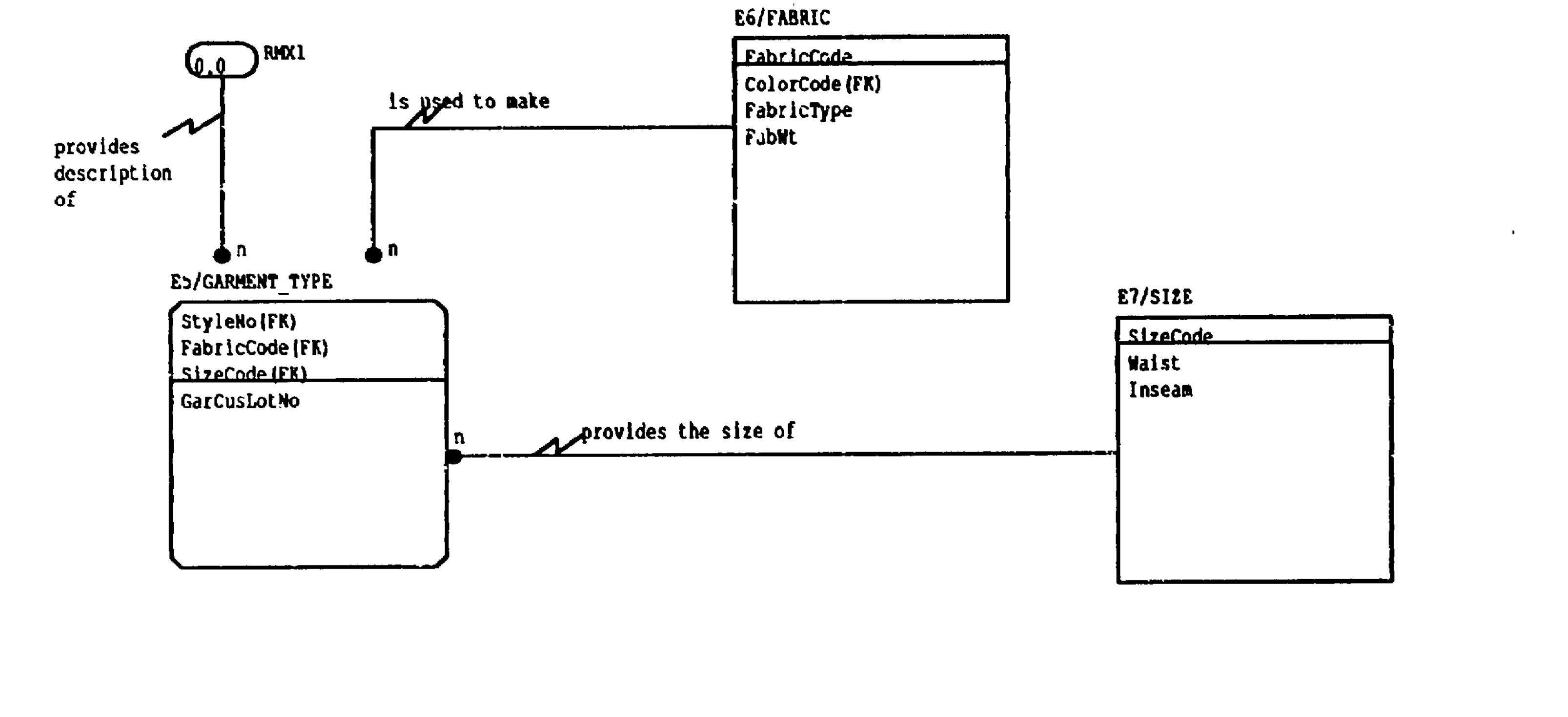


NODE:	TITLE:	NUMBER:
enterprise/F100-0	Product Development and Description	RMX1

USED AT:	AUTHOR : Rajeev Malhotra PROJECT: enterprise COMPANY: GEORGIA TECH. NOTES : 1 2 3 4 5 6 7 8 9	DATE: 19/7/89 REV.: 2/10/89	X WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: enterprise/F100-1	TITLE: Product Development and Description	NUMBER: RMX2

USED AT:	AUTHOR : Rajeev Malhotra PROJECT: enterprise COMPANY: GEORGIA TECH. NOTES : 1 2 3 4 5 6 7 8 9	DATE: 19/7/89 REV.: 4/10/89	X	WORKING	READER	DATE	CONTEXT:
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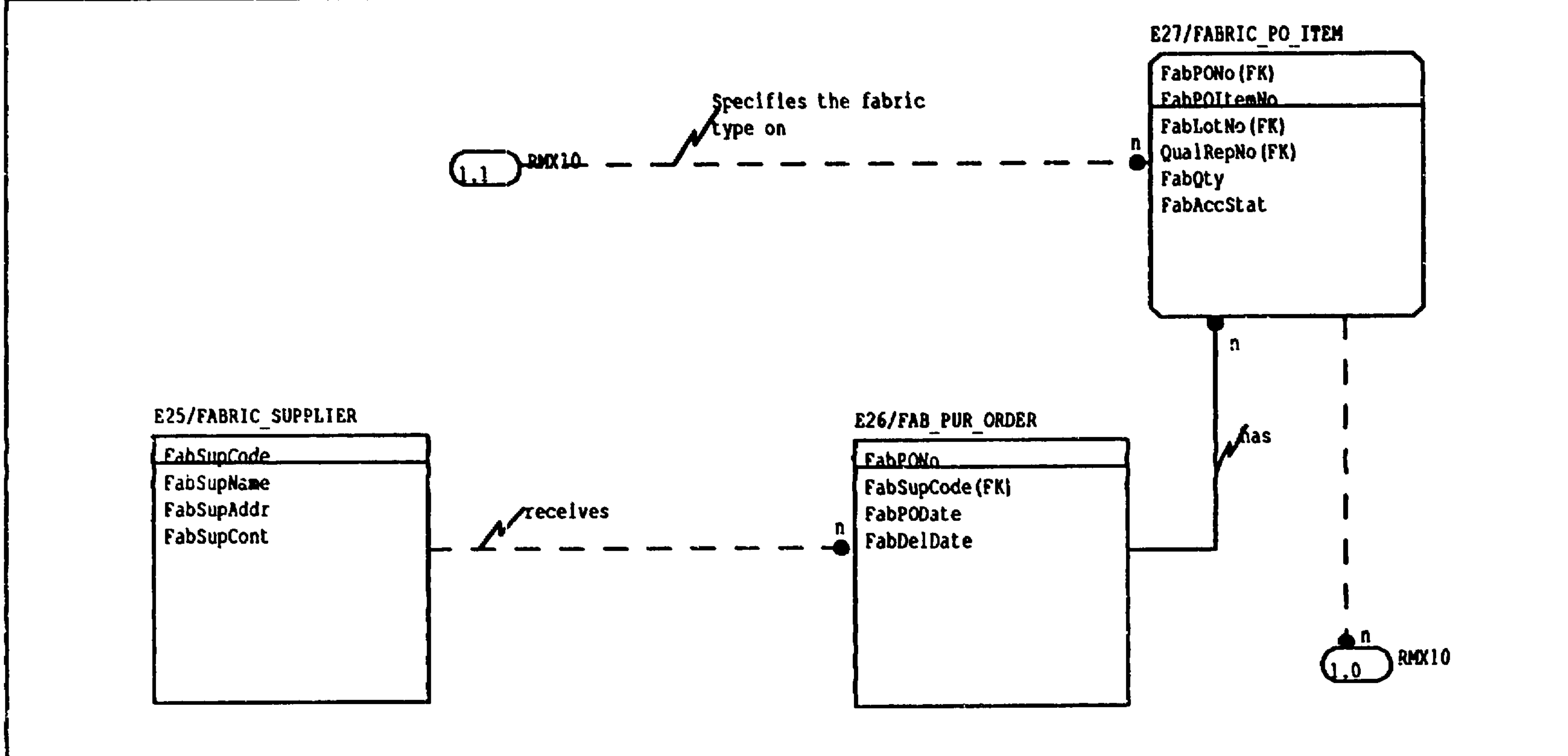
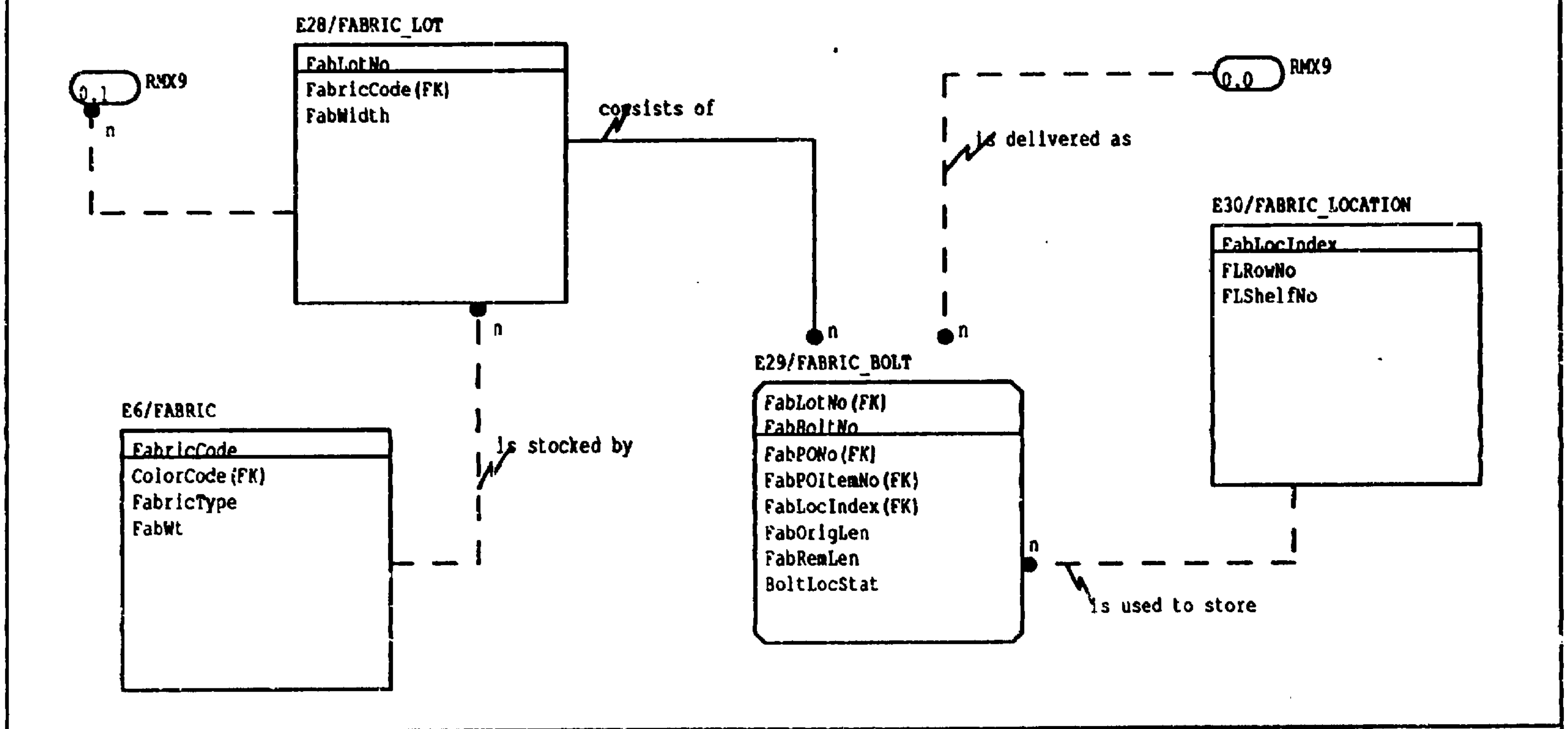


NODE:	TITLE:	NUMBER:
enterprise/F140-0	Fabric Procurement	RMX9

USED AT:	AUTHOR : Rajeev Malhotra PROJECT: enterprise COMPANY: GEORGIA TECH. NOTES : 1 2 3 4 5 6 7 8 9	DATE: 19/7/89 REV.: 10/9/89	X WORKING DRAFT RECOMMENDED PUBLICATION

READER	DATE

CONTEXT:



NODE:	TITLE:	NUMBER:
enterprise/F14[illegible]-1	Fabric Procurement	RMX10

USED AT:	AUTHOR : Rajeev Malhotra PROJECT: enterprise COMPANY: GEORGIA TECH. NOTES : 1 2 3 4 5 6 7 8 9	DATE: 24/7/89 REV.: 6/10/89	X	WORKING	READER	DATE	CONTEXT:
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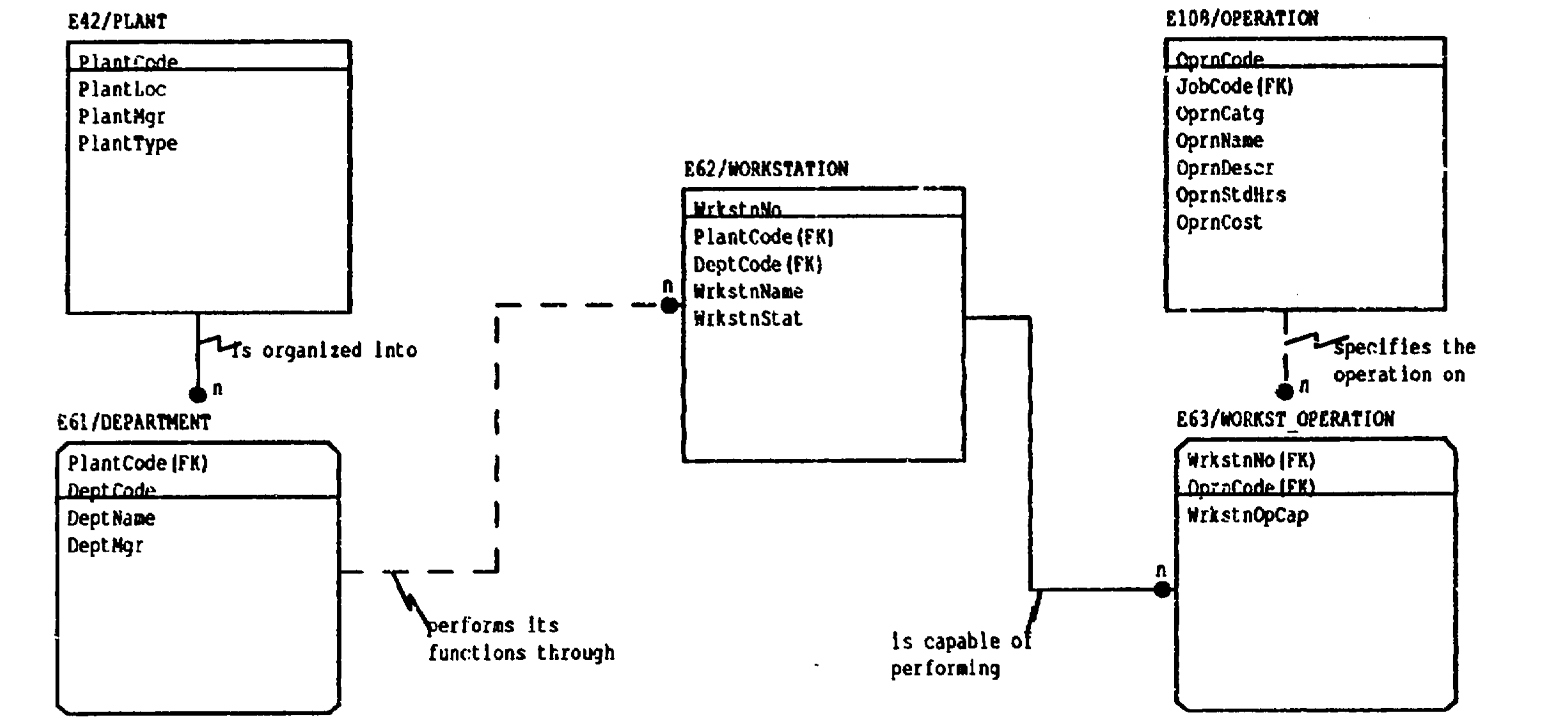

NODE:	TITLE:	NUMBER:
enterprise/F240-0	Manufacturing Resources - Equipment	RMX22

USED AT:

AUTHOR : Rajeev Malhotra
PROJECT: enterprise
COMPANY: GEORGIA TECH.
NOTES : 1 2 3 4 5 6 7 8 9

DATE: 6/10/89
REV.: 6/10/89

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	RECOMMENDED		
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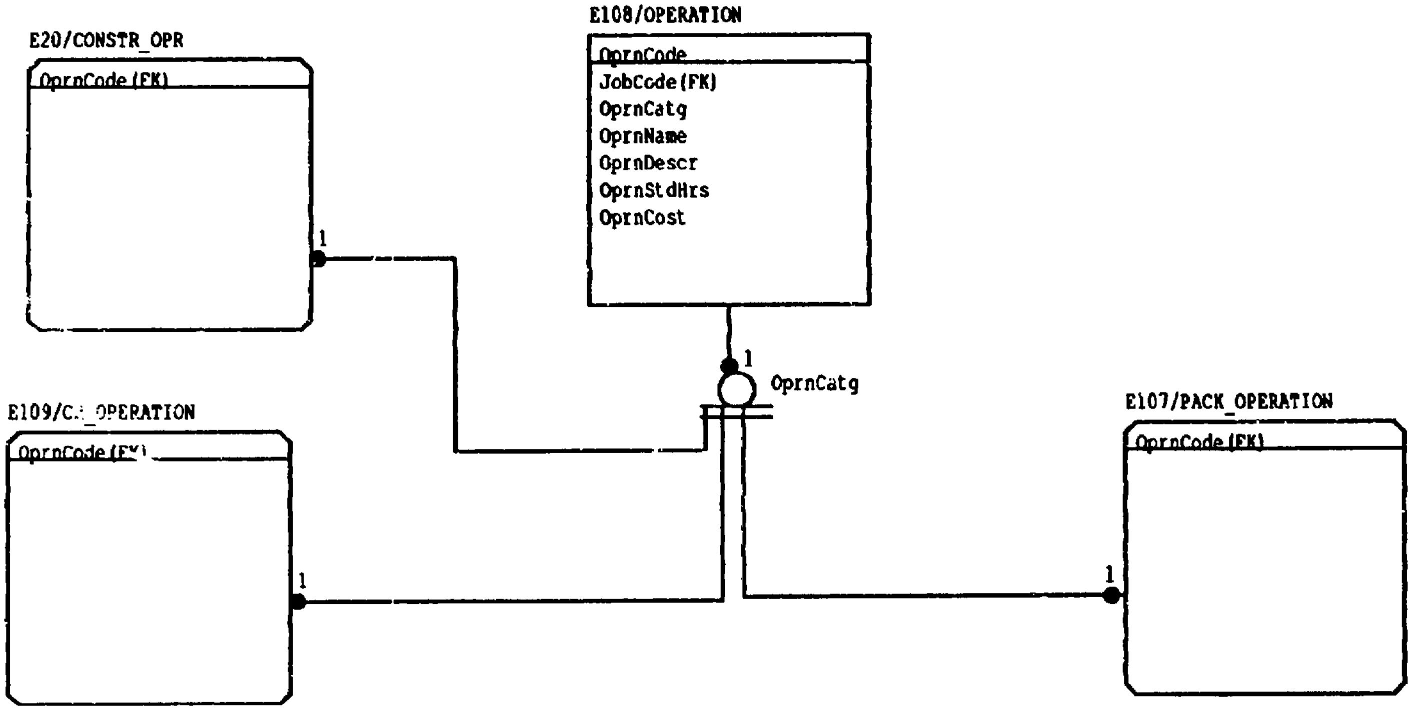
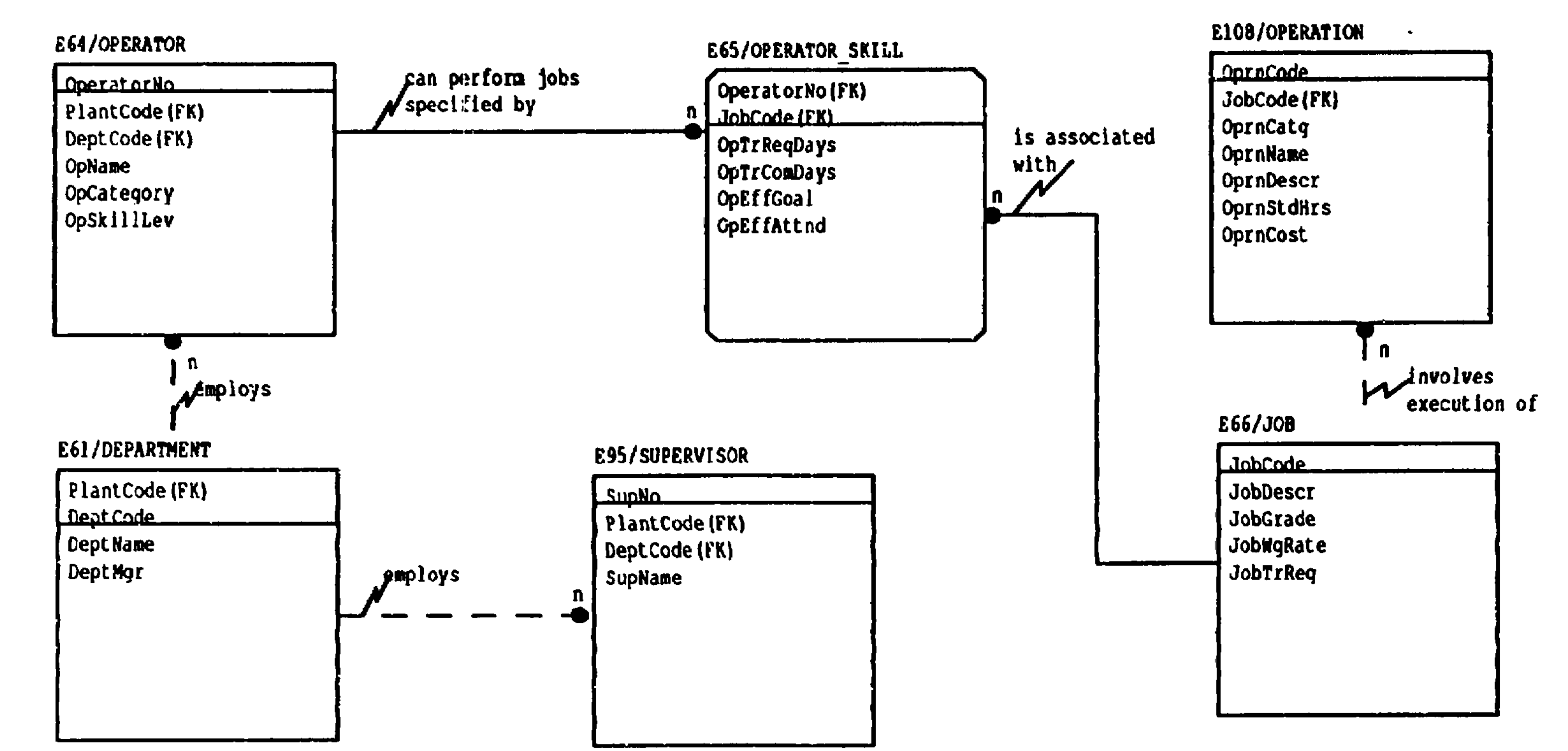


NODE: enterprise/F245-0

TITLE: Types of Operations

NUMBER: RMX40

USED AT:	AUTHOR : Rajeev Malhotra PROJECT: enterprise COMPANY: GEORGIA TECH. NOTES : 1 2 3 4 5 6 7 8 9	DATE: 25/7/89 REV.: 6/10/89	X WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: enterprise/F250-0	TITLE: *Manufacturing Resources - Human*	NUMBER: RMX23

DEFINITIONS OF TERMS USED IN THE INFORMATION MODEL

1 STYLE

Style describes the style of the garments for manufacturing. Each garment style is developed for a particular customer.

Primary Key Attributes

StyleNo: *Style Number* is the identification number for the style.

Non-key Attributes

CustomerCode: FK CUSTOMER (4).

ModelNo: FK CONSTR_DETAIL (3).

BasPatNo: FK BASE_PATTERN (13).

RunNo: FK PATTERN (14).

FitNo: FK FIT (2).

StyCreDate: *Style Creation Date* is the date on which the style is created.

2 FIT

Fit is a collection of vital measurements associated with various sizes of garments to be produced.

Primary Key Attributes

FitNo: *Fit Number* is the identification number of the fit.

Non-key Attributes

GraTabNo: FK GRADE_TABLE (11).

MeasInstr: *Measuring Instructions* are the instructions provided with the fit regarding measurements. The pattern maker uses these instructions to measure the pattern.

3 CONSTR_DETAIL

Construction Detail describes the construction features for the garment style (e.g. style and position of front pocket) and the materials required for each of these features (e.g., type of pocket trim).

Primary Key Attributes

ModelNo: *Model Number* is the identification number for the construction detail.

Non-key Attributes

ProcPlanNo: FK PROCESS_PLAN (23).

CDCreator: *Construction Detail Creator* is the person who creates the detail.

CDCreDate: *Construction Detail Creation Date* is the date on which the detail is created.

4 CUSTOMER

Customer is the party for whom the garments are manufactured.

Primary Key Attributes

CustomerCode: *Customer Code* is the identification code for the customer.

Non-key Attributes

CustName: *Customer Name* is the name of the customer.

CustAddr: *Customer Address* is the contact address of the customer.

CusConPer: *Customer Contact Person* is the person designated by the customer to deal with the enterprise.

5 GARMENT_TYPE

Garment Type describes the garments of a particular style with regards to its fabric type and size.

Primary Key Attributes

StyleNo: FK STYLE (1).

FabricCode: FK FABRIC (6).

SizeCode: FK SIZE (7).

Non-key Attributes

GarCusLotNo: *Garment Customer Lot Number* is the lot number assigned to a type of garments by the customer.

6 FABRIC

Fabric identifies each distinct type of fabric used in garment manufacturing. Fabrics are distinguished from each other by their weave, material, weight and color.

Primary Key Attributes

FabricCode: *Fabric Code* is the identification code assigned to each type of fabric.

Non-key Attributes

ColorCode: FK COLOR (82).

FabricType: *Fabric Type* is the description of the type of the fabric. For example, 100% cotton denim.

FabWt: *Fabric Weight* is the weight per unit area of the fabric. It is a measure of the fineness of the fabric and may be required to determine the process parameters.

7 SIZE

Size specifies the size of a garment. The size of trousers is specified by the waist and inseam measurement (e.g. 32/32, 32M, etc.)

Primary Key Attributes

SizeCode: *Size Code* is a code assigned to each size of the garment. For trousers, there is a unique size code for each waist and inseam combination.

Non-key Attributes

Waist: *Waist* is the measurement of a trouser at the waist.

Inseam: *Inseam* is the inseam length of a trouser.

8 SAMPLE_REQ

Sample Request is a request sent by the customer for sample garments. Each request can be used to obtain samples of various types.

Primary Key Attributes

SReqNo: *Sample Request Number* is a serial number assigned to each request for samples received from the customers.

Non-key Attributes

CustomerCode: FK CUSTOMER (4).

SReqDate: *Sample Request Date* is the date on which the sample request is received.

SDelDate: *Sample Delivery Date* is the date on which the samples need to be delivered.

SActDelDate: *Sample Actual Delivery Date* is the date on which the samples are actually delivered.

SSpeInstr: *Sample Special Instructions* are the special instructions sent by the customer for preparing samples. For example, the customer may specify how the samples have to be packed, shipped, etc.

9 SAM_REQ_ITEM

Sample Request Item is a line item on SAMPLE_REQ (8) specifying the GARMENT_TYPE (5) and the quantity of the sample garments requested. There is one sample request item for each type of garment requested.

FabAccStat: *Fabric Acceptance Status* specifies whether the fabric has been accepted for stocking after inspection or has been marked for return to the supplier.

28 FABRIC_LOT

Fabric Lot identifies each type of fabric item in the inventory distinguished by the fabric type, as specified by FABRIC (6), and the width. Distinction based on width is required to select appropriate marker for cutting the fabric.

Primary Key Attributes

FabLotNo: *Fabric Lot Number* is the identification number for fabric lot.

Non-key Attributes

FabricCode: FK FABRIC (6).

FabWidth: *Fabric Width* is the width of the fabric in the lot.

29 FABRIC_BOLT

Fabric Bolt is a roll of fabric. The fabric suppliers supply the ordered length of fabric on one or more bolts.

Primary Key Attributes

FabLotNo: FK FABRIC_LOT (28).

FabBoltNo: *Fabric Bolt Number* is the identification number of each fabric bolt.

Non-key Attributes

FabPONo: FK FAB_PUR_ORDER (26).

FabPOItemNo: FK FABRIC_PO_ITEM (27).

FabLocIndex: FK FABRIC_LOCATION (30).

FabOrigLen: *Original Fabric Length* is the initial length of the fabric on a bolt.

FabRemLen: *Remaining Fabric Length* is the current length of the fabric on a bolt. All the fabric on a bolt may not get used in a single cut.

BoltLocStat: *Bolt's Location Status* is the location status indicating whether a bolt is in storage or has been moved to the cutting room.

30 FABRIC_LOCATION

Fabric Location is the storage location for fabric bolts in the fabric warehouse. Each location is a rack. The racks are arranged in aisles.

Primary Key Attributes

FabLocIndex: *Fabric Location Index* is the code assigned to each storage location in the fabric warehouse.

Non-key Attributes

FLRowNo: *Fabric Location Row Number* is the aisle number for the storage location.

FLShelfNo: *Fabric Location Shelf Number* is the shelf number for the location.

31 MATERIAL_VENDOR

Material Vendor is a suppliers for materials such as trim, threads, accessories, tickets, tags and labels.

Primary Key Attributes

MatVenCode: *Material Vendor Code* is the identification code assigned to each vendor of construction materials.

Non-key Attributes

MatVenName: *Material Vendor's Name* is the name for the material vendor.

MatVenAddr: *Material Vendor's Address* is the contact address of the vendor.

MatVenCont: *Material Vendor's Contact* is the contact person of the vendor with whom the enterprise deals.

MatVenRatg: *Material Vendor's Rating* is the performance rating of the vendor.

facturing plant. For example, a plant may have sewing and finishing departments.

Primary Key Attributes

PlantCode: FK PLANT (42).

DeptCode: *Department code* is the identification code assigned to each department.

Non-key Attributes

DeptName: *Department Name* is the descriptive name of the department.

DeptMgr: *Department Manager* is the person who manages the department.

62 WORKSTATION

Workstation is a single machine or a group of related machines used to perform unit manufacturing operations. A workstation has the flexibility to perform more than one operation, but at any given time, it is set to perform one particular operation.

Primary Key Attributes

WrkstnNo: *Workstation Number* is the identification number assigned to each workstation.

Non-key Attributes

PlantCode: FK PLANT (42).

DeptCode: FK DEPARTMENT (61).

WrkstnName: *Workstation Name* is the descriptive name for the workstation.

WrkstnStat: *Workstation Status* indicates whether the workstation is available for use or not.

63 WORKST_OPERATION

Workstation Operation is a construction operation that a particular workstation is capable of performing. This entity also gives the capacity of the workstation for this particular operation.

Primary Key Attributes

WrkstnNo: FK WORKSTATION (62).

ConOpeNo: FK CONSTR_OPR (20).

Non-key Attributes

WrkstnOpCap: *Workstation's Operation Capacity* is the capacity of the workstation in units per hour.

64 OPERATOR

Operator is the human responsible for operating the workstation to perform an operation.

Primary Key Attributes

OperatorNo: *Operator Number* is the identification number assigned to each operator.

Non-key Attributes

PlantCode: FK PLANT (42).

DeptCode: FK DEPARTMENT (61).

OpName: *Operator's Name* is the name of the operator.

OpCategory: *Operator Category* is the category assigned to the operators based on the nature of their work. For example, a worker could be a utility person, a trainee, etc.

OpSkillLev; *Operator Skill Level* indicates the skill level and proficiency of the operator.

65 OPERATOR_SKILL

Operator Skill is the skill and training level of the operator to perform a particular job. An operator may be skilled in one or more jobs and may be under training for a few more.

Primary Key Attributes

OperatorNo: FK OPERATOR (64).

JobCode: FK JOB (66).

Non-key Attributes

OpTrReqDays: *Required Operator Training Days* specifies the number of days required to train for the job.

OpTrComDays: *Completed Operator Training Days* specifies the number of days of training completed.

OpEffGoal: *Operator Efficiency Goal* is the desired efficiency level at the end of training.

OpEffAttnd: *Attained Operator Efficiency* is the current level of efficiency of the operator on the job.

66 JOB

Job is a generic entity for a class of construction operations that are similar in nature as far as the operator skills and workstation requirements are concerned. For example, serging of trouser back and front panels are different operations but both fall under the same job category.

Primary Key Attributes

JobCode: *Job Code* is the identification code assigned to each job.

Non-key Attributes

JobDescr: *Job Description* is the description of what the job entails.

JobGrade: *Job Grade* is the grade assigned to the job based on the level of skill required to perform it.

JobWgRate: *Job Wage Rate* is the wage rate associated with the job.

JobTrReq: *Job Training Requirement* is the description of training requirements for the job.

68 CUT_RM_SCHEDULE

Cutting Room Schedule is the production schedule for the cutting department. Productions orders scheduled for cutting in each production period are recorded here.

Primary Key Attributes

CRProdPeriod: *Cutting Room Production Period* is the period for which production is to be scheduled.

Non-key Attributes

CRSModDate: *CR Schedule Modification Date* is the date on which the schedule was last modified.

CRSModPer: *CR Schedule Modifying Person* is the person responsible for making the schedule change.

69 CUT_RM_SCH_ITEM

Cutting Room Schedule Item is the line item on CUT_RM_SCHEDULE (68) specifying a production order scheduled for a particular period. More than one production orders can be scheduled for cutting each period.

Primary Key Attributes

CRProdPeriod: FK CUT_RM_SCHEDULE (68).

CutItemNo: *Cutting Schedule Item Number* is the serial number of the schedule item on the schedule.

Non-key Attributes

ProdOrdNo: FK PRODUCTION_ORDER (48).

CutStDate: *Cut Start Date* is the date on which work on the order is scheduled to begin in the cutting room.

CutExFinDate: *Cut's Expected Finish Date* is the date on which work on the order is expected to finish.

CutAcFinDate: *Cut's Actual Finish Date* is the date on which the work is actually finished.

70 CR_ASSIGNMENT

Cutting Room Assignment is an assignment of cutting room resources to perform an operation associated with a particular production order.

Information Model --> DBMS

Software 'Jtility

Purpose:

- Set up a DBMS from INFO Model
- SQL Commands
- Implemented in Several Modules

Working:

IDEF$_1$x Model Files

SQLGEN1

Table listing Entities, Attributes, Attribute Definitions

SQLGEN2

Map

Log

Consistency Checking
Attribute Ownership
Attribute Type

Errors

SQLGEN3

SQL Commands for Setting Up Database Files

$\boxed{\text{SQLGEN4: Control Program}}$

Update:

SQLALT1: Compiles Changes Made to Info Model Since Last Time

SQLALT2: Generates Updates: Changes in Entity Names, Addition of New Entities and Attributes

cf. Change of Attribute Name or Type, Deletion of Attributes: LOG File -- DBA to carry out modification

Dynamics Model

* $IDEF_2$

Facility Submodel:

Resources Used by System
Materials/Machines/Humans

Entity Flow Submodel:

Flow of Products/Info is Described

Resource Disposition Submodel:

Disposition of Resources as They Become Available are Described

System Control Submodel:

Activities Controlling Flow of Entities are Described

* Shortcomings of $IDEF_2$

Lack of Integration

(Function/Info)

Duplication of Effort

No use of F/I

Developed Independently of F/I

Current Efforts

* $IDEF_2$ + SIMAN Methodology: IFEM

* Single Integrated Framework
  (F+I+D)

Education

* Mr. Rajeev Malhotra, GRA

  --> Ph.D. Dissertation

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[3] Jayaraman, S., "Design and Development of an Architecture for Computer-Integrated Manufacturing in the Apparel Industry, Part I: Basic Concepts and Methodology Selection," Textile Research Journal, To Appear in April 1990.

[4] Malhotra, R., and Jayaraman, S., "Design and Development of an Architecture for Computer-Integrated Manufacturing in the Apparel Industry, Part II: The Function Model," Textile Research Journal, To Appear in May 1990.

[5] Jayaraman, S., "On a Manufacturing Enterprise Architecture," IJCAI '89 (International Joint Conference on Artificial Intelligence) Workshop on Manufacturing, Detroit, MI, August 21-25, 1989.

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FASHION INSTITUTE OF TECHNOLOGY

BUNDLE SYSTEM VS UPS

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

BUNDLE SYSTEM VS UPS

(PAPER NOT AVAILABLE)

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GEORGIA TECH

FLEXIBLE WORK GROUPS

APPLICABILITY OF FLEXIBLE WORK GROUP METHODS TO THE MANUFACTURE OF MILITARY UTILITY TROUSERS

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February, 1990

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Defense Electronics Supply Center
United States Department of Defense

1.0 *Introduction and Scope of Project*

1.1 Introduction

Increasing productivity in the U. S. apparel industry would be a step toward fortifying our defenses against overseas competition. Industrial engineers and operations research analysts have been studying the concept of flexible manufacturing for some time. This idea can go a long way toward raising productivity levels in manufacturing.

There are two ways to achieve flexible manufacturing: one based on computer-integrated "cells" of machines, and the other on people in "flexible work groups" (FWGs), popularly known as modular manufacturing. The latter is important to the apparel industry where it is not yet cost-effective, or even feasible, to fully automate the manufacturing process. In other industries, this philosophy has become a highly competitive manufacturing strategy because of its capability to quickly and efficiently adapt to changes in product mix, demand, and design.

In the apparel industry, FWGs are "teams" of workers cross-trained in several operations which carry out entire assembly processes and are compensated as a group rather than individually. The emphasis is on group effort and employee involvement, quality at the source, and short throughput time. This concept is being used in a number of production areas similar to apparel, such as shoe and curtain manufacture.

In addition to the impact on productivity, there is likely to be an equally important impact on quality. People working together as a team are likely to be more consistent in the accuracy with which they perform their jobs. In this setting, there is the opportunity for real-time feedback as to fabric and sewing defects before the garment is completely assembled This translates into raw material savings as well as a reduction in required production repetitions. In addition, the team members are apt to establish more pride in their work and motivation to assemble defect-free garments in their group. Producing high quality, defect-free garments is necessary to gain consumer confidence and to increase the competitiveness of U. S. apparel makers with overseas manufacturers.

A third benefit of the modular philosophy is a significant reduction in work-in-process (WIP) inventory, and the corresponding reduction in required plant floor space and carrying costs. The savings associated with reduced inventory are reflected along the entire inventory pipeline, including the supplier level. Furthermore, the physical reduction in WIP can greatly reduce flow congestions and thereby enhance material control.

The FWG concept brings a new set of challenges. For example, the question of how the manufacturing processes will actually be carried out becomes

a much more complex one. This involves not only the layout of the equipment, but also a careful evaluation of which operations will be incorporated into the work module, which operators will work in the group, and which operator will perform which operation. In addition, the overall manufacturing process is likely to require a much more complex control strategy and tracking system for order progress to be updated.

The FWG concept brings social as well as technological challenges. First, the implementation of a FWG requires a cooperative and conscientious attitude from those persons working in the group. This may be brought about by the use of proper training and various incentive programs. Operator absenteeism becomes a problem when team operation depends upon everyone being present and contributing. In addition, the team concept requires a great deal more self-management offering an even greater challenge to the workers involved. This is also likely to mean that plant managers must become more flexible and must set more realistic goals for meeting market conditions.

This project undertakes the study of the flexible work group concept and how it can be applied to trouser manufacturing. The advantages and disadvantages of this concept will be assessed relative to conventional approaches in the manufacture of a comparable simple garment as the military utility trouser. In addition, a laboratory environment, known as a Virtual Manufacturing Enterprise (VME) will be created in which to perform the study and to demonstrate the research results, as well as to provide an important environment for use in other research tasks.

1.2 Scope of the Project

The objective of this program is to investigate the applicability of flexible work group methods to the manufacture of military utility trousers. Both quantitative and qualitative techniques will be used to evaluate these methods through an emulation of flexible work groups within an apparel manufacturing facility. Recommendations will be made on how to best implement the FWG philosophy for trouser manufacturing. These results can later be extended to the production of other types of garments.

This study will result in two distinct outcomes. First are the recommendations for the application of FWGs to the manufacture of military utility trousers. Second is the establishment of a virtual manufacturing enterprise which will provide a vehicle for demonstrating research results. Furthermore the VME will continue to be a valuable laboratory environment in which to extend this work.

2.0 *Project Activities*

2.1 Study of Existing Flexible Work Groups

Although the trade journals seem to have a new article every month concerning modular manufacturing, there has been very little published in the technical journals concerning this concept with specific regard to apparel manufacturing. However, the concept of flexible manufacturing offers an abundance of technical publications in such journals as *Operations Research, AIIE Transactions, European Journal of Operational Research, International Journal of Production Research*, among others, as well as many books published on the subject. All of this literature is being reviewed as a means of learning how the concept of flexible work groups can be applied in the apparel industry.

In addition to the literature, the modular concept is currently being implemented in various ways at apparel manufacturing plants throughout the country. We plan to visit several of these plants in the Atlanta area to observe how the concept operates in practice, as well as to hold discussions with management concerning planning and implementation issues.

2.2 Study of Current Work Methods

This task has been and is being accomplished by reviewing the literature related to apparel manufacturing methods. In addition, site visits to apparel manufacturing plants have been and will be used to extend the understanding of these methods. We are particularly interested in the progressive bundle system and the unit production system, since these seem to be the methods most widely used in addition to the modular concept. We also have had significant input from the research technicians at our demonstration center at Southern Tech, where a full demonstration of the facility was provided for this research team.

2.3 Theoretical Analysis of Flexible Work Groups

Based on what can be learned from the first two tasks, the initial task in the theoretical analysis of the FWG concept is to determine what questions need to be addressed. A review of the literature related to the appropriate questions will be an ongoing process during the course of the analysis. The initial mathematical model deals with the problem of assigning workers to stations (see figure 1). Specifically, the need for knowing the assortment of skills belonging in a group and how the workers should be cross-trained is a very relevant question. Ideally there should be a productive mix of skills in the group, but also the group should be able to remain productive when some members are absent. Other avenues of investigation using this initial model are as follows:

1. Improving the output rate by making "dynamic" assignments in which workers might be rotated among machines in the midst of a run. This allows the appropriately skilled and fast workers to track bubbles of WIP and dissolve them.

2. Finding the appropriate incentives (marginal pay) for the workers to function as a group. That is, the worker whose speedup will most help the group will appropriately have the largest incentive pay.

3. Determining which tasks a new worker should be trained in to best support the group with whom s/he will be working.

4. Proving that an optimally configured work group does not require any worker to be trained in "too many" skills.

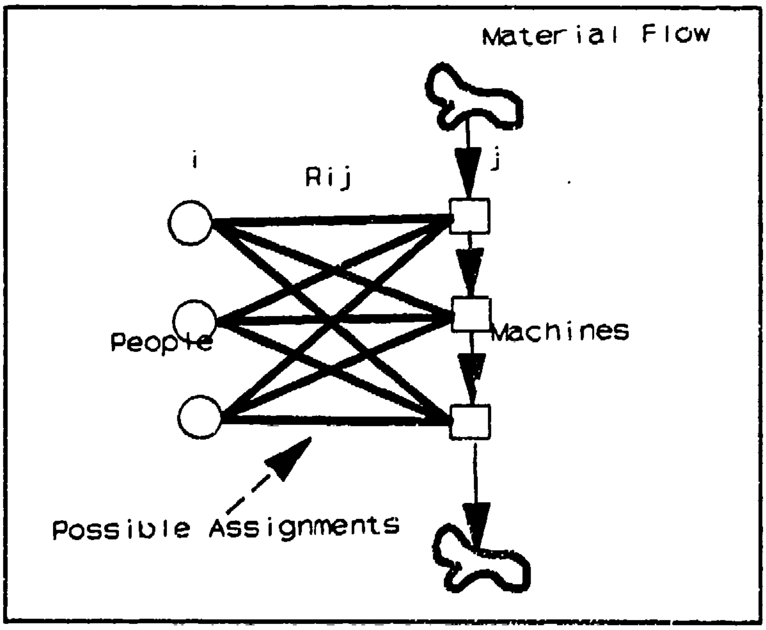

Figure 1. Assignment of Workers to Machines

In studying work assignments that are "dynamic," that is they can change over time to take best advantage of the current WIP levels, the model can be solved to determine how much time each worker should spend at each stations for which s/he is qualified. The problem is, this does not determine a schedule for dynamically making these assignments. The question of determining the schedule is as yet unanswered. If this can be resolved, the marginal profit expected by providing additional worker training for any worker, and the marginal profit

expected by assigning a worker to a particular station can also be found. A more specific discussion of the worker assignment problem is given below.

There are n workers and m machines. The machines are those of a production line and work flows from machine j to machine j+1. All jobs are identical and all jobs flow through all machines exactly once.

Each worker has a "skill profile" which tells how fast they can work on each machine. The skill profile for worker i is an m-dimensional vector (r_{ij}), in which r_{ij} is the rate at which worker i can produce at machine j.

Fixed assignment problem: Assign n = m workers to m machines to maximize the production rate of the line.

We can solve this in polynomial-time, i.e. quickly enough for the solution to be practical. We do this by suggesting rates for the production line and then checking to see whether it is possible to assign workers to machines so that this rate is achieved. In the general step we consider whether rate r is achievable by the line; delete all worker-machine assignments that have production rate < r; and solve an "assignment problem" to test for feasibility. (This can by done within polynomial time. Special purpose procedures can be quite fast; it would probably still be sufficiently fast to use a general purpose linear programming code.) If the rate r is achievable, then we guess a higher rate r'; otherwise we guess a lower rate r' and check it for feasibility. In short we do binary search for the resultant rate of the line, checking each candidate rate for feasibility by solving an assignment problem. The worst-case effort is $O(n^2 \log r_{max})$; that is we need solve no more than $O(\log r_{max})$ assignment problems, each one requiring no more than $O(n^2)$ work.

The assignment derived above is the fixed assignment that maximizes the production rate of the line. However, greater production rates can sometimes be achieved if the workers switch assignments during the schedule. For example consider the 3 workers given by the following skill profiles: (9,9,9); (1,1,1); (1,1,1). Worker #1 is much faster than the other two. No fixed assignment of these workers can produce at a rate greater than 1. However a faster (average) rate can be achieved by moving the fast worker in such a way as to track a bubble of work-in-process inventory through the system. That is, the line should first operate with worker #1 assigned to machine #1; then after some time t, worker #1 should switch with the worker at machine #2; again after time t, worker #1 should switch with the worker at machine #3. After 3t time the line will have produced at rate 3-2/3.

Now we know that it might be worth considering rotating workers. (In fact, sometimes workers must be rotated, as when there are fewer workers than

machines.) If we are willing to rotate workers, how great a production rate can we achieve and by what schedule do we rotate them?

Flexible assignment problem: Give a schedule of assignments of n <= m workers to m machines to maximize the average production rate of the line.

We do not know how to solve this yet. We can solve a continuous version of the previous problem: maximize the minimum AVERAGE production rate over all machines. The solution to this linear program gives an upper bound on the largest achievable production rate, but we do not yet know whether it is achievable.

(Incidentally, we have examples showing that this bound can be arbitrarily larger than the solution to the fixed assignment problem: a simple example is to replace the worker (9,9,9) with a fantastically fast worker (9M,9M,9M). Then no fixed assignment can produce at rate faster than 1, but the rotating assignment can achieve average production rate of 3M + 2/3. The difference in these two rates clearly grows with M.)

The solution to this linear program tells what proportion of their time each worker should spend on each machine, but it does not tell when or how this should be coordinated with the other workers. We are now trying to determine this. We can show that there are no more than m+n assignments that will give the optimal average time on each machine for each worker - but it is not clear how to sequence the assignments to achieve the corresponding production rate. We are looking at heuristics that sequence the assignments so that the bottleneck machine moves from the back of the line to the front; equivalently, the faster workers are first assigned at the front of the line and later reassigned to the subsequent machines.

2.4 Development of the Virtual Manufacturing Enterprise

The conventional wisdom is that manufacturing enterprises can only be studied in the field. However, such studies are very expensive and therefore very limited. To determine the impact of a change to the system, the actual system must be changed. Since components cannot be isolated and studied in a laboratory environment, it is very difficult to understand the interactions among components. Also, it is impossible to field study conceptual systems which have not yet been built.

A major difficulty with studying a manufacturing enterprise in a laboratory is that the methodology for adequately emulating a field environment has not been developed. This can be accomplished by modeling each component of the manufacturing enterprise as a software module which emulates the real component. These software modules may run on a distributed network of computers, or perhaps in a multitasking environment such as UNIX.

Such a facility would consist of hardware as well as virtual components, networked with other facilities, such as the Apparel Manufacturing Technology Center's demonstration center. Thus, the first task in the VME development has been to establish a functional description of the system, defining what kinds of tasks will actually be performed and what questions will be addressed. This physical description of the VME has been used as the basis for specifying the hardware requirements. We will be implementing the VME via SUN workstations, working in the UNIX operating environment and the C++ programming language.

The VME facility is physically located in the Interactive Design and Analysis Laboratory at Georgia Tech. This lab contains twelve wall mounted high resolution Chromatics CX-1300 color graphics display units, two table-top Chromatics CX-1300 color graphics display units, six IBM 3179 terminals, five IBM PS/2-50s, and a large screen projector. This configuration allows flexible display of graphical and tabular information to the design team. In the UNIX environment the graphical interface will be accomplished with X-Windows. This facility is connected to the campus-wide GT Network over which other computing resources can be accessed. The necessary linkages to the AMTC demonstration center will be made as a part of this development. At the demonstration center, an IBM AS-400 mini-computer is available for data collection and transfer to the VME laboratory.

This virtual manufacturing enterprise will provide more than the capability to simulate the actual factory; the goal is to emulate the system. With each functional component modeled in software, and each of these operating independently of the others, it will be possible to dynamically interact with one or more processes while the remainder of the factory continues to operate as normal. In a real industrial setting, this is how such an interruption would actually transpire. If the automatic belt loop maker experienced a breakdown, it does not mean that the entire sewing room must shut down in order to deal with that problem. So will the VME operate.

The ability to study alternative configurations and design concepts for the FWG, and the ability for real-time tracking of the system operation will be inherent to the design of the facility. During the course of this project, the system will be developed as a prototype or emulation of modular manufacturing. We plan to establish an experimental FWG at AMTC's demonstration center. This group will be cross-trained in the necessary operations for assembling trousers. This group will be utilized in two ways. First, important data can be collected from the actual operation of the group. Second, the ideas and theories developed during the analysis will be tested by this experimental group. Expansion toward a full-fledged factory emulator will be investigated, focusing on the design and implementation issues.

The design of the large scale architecture of the VME has been completed. This has been quite challenging since the VME must:

A. run in either real time or simulated time: that is, time must be scalable;
B. run on a network, with pieces of the VME distributed throughout the network, and at the same time all components be synchronized;
C. be independent of whether pieces are real or software emulation;
D. allow different pieces to operate on different time scales (to allow studying some parts more carefully than others);
E. be recursive in design so that each piece can be composed of still more pieces (again allowing us to model in more detail where needed).

A simple initial prototype has thus far been developed and can be demonstrated. This model shows the various workstations and the WIP levels at each of those stations, and allows for user interaction in that a worker may be reassigned to a different workstation when WIP levels become out of balance. This prototype is important in that it shows that we can indeed do more than simulate since reassigning a worker does not interrupt the other workstations in any way. This means that in this prototype each workstation is operating in software as an independent entity. The next step will be to determine how this prototype can be extended to operate in a networked environment.

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

FLEXIBLE WORK GROUPS

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NORTH CAROLINA STATE UNIVERSITY

PLY SEPARATION

A Performance Study of the Jet Sew "Clupicker" Feeding System

by

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ABSTRACT

As part of the Defense Logistics Agency's contract titled, "Automated Technology for Apparel Manufacturing," a study was conducted to evaluate the flexibility and the production efficiency of the Jet Sew "Clupicker" ply separation system using a variety of military apparel fabrics.

The ply separation system was tested using the Turn & Divide (T&D) module developed by ARK, Incorporated. Tests were conducted at the $(TC)^2$ National Apparel Demonstration Center in Raleigh, North Carolina. Twelve fabrics used in military apparel were selected for the study. The fabrics ranged from 100% nylon suit lining to 100% wool dress trouser material.

The mechanical adjustments on the "Clupickers" were set based upon the fabric physical properties. A total of 1000 picks were monitored for each fabric. The results of performance testing clearly indicated the high mechanical efficiency ($\geq$99.5%) of the ply separation system over the range of fabrics tested. Only two fabrics had efficiencies less than 100%.

The gap width was shown to be the most critical mechanical adjustment for insuring optimum performance. This adjustment can be preset by measuring the 2-ply compressed thickness of the fabric. Continued research is needed to study and improve the gap width adjustment. This improvement would enhance the acceptance of the feeding system.

Introduction

The Defense Logistics Agency (DLA) contracted the College of Textiles at North Carolina State University to develop an automated work cell for assembling small parts. Specifications were written for the design and construction of modules to form an automated work cell that would take cut parts, spread face-to-face, and produce pocket subassemblies. The remaining discussion will focus on the module developed to separate and feed garment parts.

A feeding module, called the Turn & Divide (T&D) Module, was designed and constructed by ARK, Incorporated. This module was designed the separate and restack cut parts into stacks of "rights" and "lefts." The module was designed around the Jet Sew "Clupicker" ply separation system.

One of the goals the DLA contract was to develop technology that would have the flexibility to produce military and civilian garments with minimum mechanical adjustments. The feeding module must be capable of separating and feeding a variety of types and styles of fabric within the range of products produced. The purpose of this study was to evaluate the flexibility and the production efficiency of the "Clupicker" ply separation system using a variety of military apparel fabrics.

Equipment

The Turn & Divide Module was installed at the $(TC)^2$ National Apparel Demonstration Center in Raleigh, North Carolina. Appendix I with the Jet Sew "CLupicker" manual describes the installation and operation of the module.

The T&D module is equipped with two "Clupickers." The "Clupickers" have a number of mechanical adjustments (refer to "Clupicker" manual). Most of these adjustments are set during installation and are not changed in production.

The primary operator adjustment is the spring compression that controls the contact force of the picker on the fabric. In order to quantity the contact force for the study, a linear scale was installed to relate adjustable spring compression to contact force as shown in Figure 1.

Another adjustment considered to be important is the gap width. The gap width is the distance between the rotating wheel and the shoe (see Figure 2). Practical experience has proven that the gap width should be adjusted when fabrics with different thicknesses are used. One industrially suggested method for

setting the gap width was to place three plies of fabric between the wheel and shoe. Then, compress the plies with the shoe and tighten the shoe in place. This procedure was tried for several fabrics, and the gap width was measured with a "feeler" gauge. The measured width compared favorably with the thickness of two plies of fabrics compressed by a micrometer. Based on this relationship, the compressed 2-ply thickness is measured and the gap width is set to that measurement.

All of the mechanical adjustments other than the gap width and the contact force were set in accordance to the manual and were not varied during the study.

Experimental Procedures

Twelve fabrics used in military apparel were selected for the study. A description of each fabric is listed in Appendix II. Table I lists the physical and mechanical properties of the fabrics. The fabrics ranged from 100% nylon suit lining to 100% wool dress trouser material. Each fabric was spread face-to-face to a height of twenty plies. The spread was vacuum compressed to 4 inches of mercury and cut using a Gerber Cutter located at (TC)[2]. The fabric was cut into 4x8 inch rectangles. After cutting, twenty-ply stacks were combined into groups of five or 100 plies for testing. Five 100-ply stacks were used.

Before the efficiency testing was begun, the 2-ply compressed thickness was measured, and the gap width was set accordingly. Next, the operational range of the contact force was determined by observing the picking performance as the spring compression was varied from low to high (0.3 TO 2.2 lbs). The spring compression was then set to at the midrange value. Table II shows mechanical settings for each fabric. The linear scale values can be converted into contact force in pounds using the following equation:

$$P = (.07496)S - (.2415) , \qquad (1)$$

where P - Contact Force (pounds)
S - Linear Scale Units.

An analysis of Table II reveals that the gap width varies greatly while the average contact force is similar for most fabrics. It is important to note that the primary operator adjustment, spring compression, does not significantly influence the performance provided the gap width is preset to the 2-ply compressed thickness measurement.

Performance testing and Analysis

Both "clupickers" on the Turn & Divide Module were set at the gap widths and spring compressions listed in Table II. Five 100-ply stacks of each fabric were taken immediately after cutting and tested. Since two pickers contacted each ply, a total of 1000 picks were monitored. The results of performance testing are shown in Table II. These results clearly indicate the high mechanical efficiency of the ply separation system over the range of fabrics tested. Only two fabrics had efficiencies less than 100%. In case of the 100% polyester lining fabric, all three "miss picks" were attributed to the variation in table height adjustment since the fabric was very thin. In the case of the camouflage ripstock fabric, all five of the "miss picks" occurred with back-to-back fabric contact. Increased spring compression may have overcome the ply-to-ply attractive forces in this case.

Summary

The results of this study have proven that the Jet Sew "Clupicker" ply separation and feeding system has the flexibility to efficiently separate the range of fabrics tested. This range includes the typical fabrics in most military apparel garments.

The gap width was shown to be the most critical mechanical adjustment for insuring optimum performance. This adjustment can be preset by measuring the 2-ply compressed thickness of the fabric. The gap width is not adjusted easily by the operator. Further research is needed to study and improve the gap width adjustment. This improvement would enhance the acceptance of the feeding system in the small contractor's plant.

This study provides an understanding of the performance and optimization of the Jet Sew "Clupicker" system. This knowledge has been incorporated into the operating manual for the Turn & Divide Module (Appendix I).

Acknowledgments

We would like to thank the (TC)^2 National Apparel Technology Center for providing technical support and use of their facilities in this study. We would also like to thank DPSC for supplying the fabrics and the Defense Logistics Agency for financial support under contract no. DLA 900-87-C-0509.

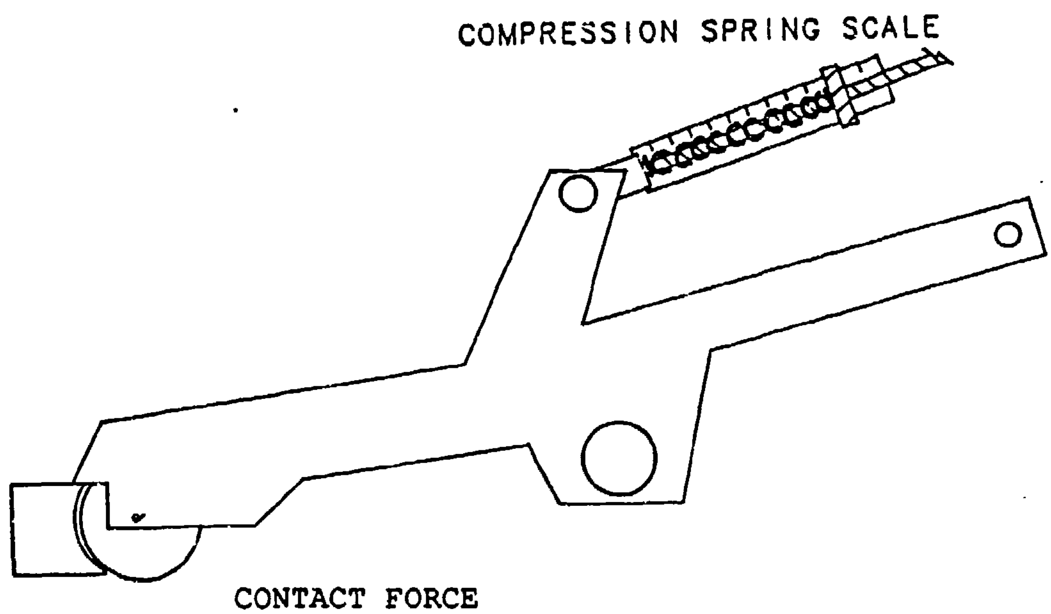

Figure 1. Clupicker compression spring adjustment for controlling fabric contact force.

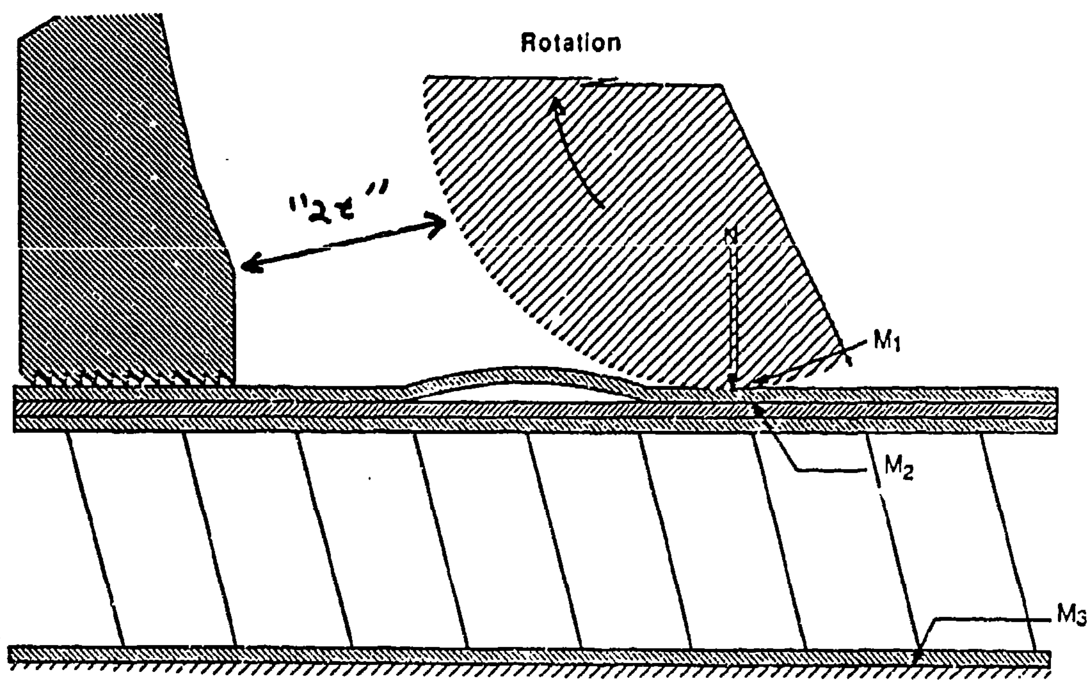

Figure 2. Illustration of the gap width between the wheel and the shoe ("2t" is compressed 2-ply thickness).

TABLE I. Fabric Physical Properties

DESCRIPTION	MIL SPEC MIL-C-	oz/yd^2	KAWABATA				
		WEIGHT	RIGIDITY	FRICTION	SURFACE	To	Tm
1 55/45 poly/wl pants	21115K (CL5)	6.51	.184	2.22	8.375	.6040	.4300
2 65/35 poly/ct shirting	43992A	3.52	.053	2.19	4.30	.3540	.2175
3 50/50 cot/nyl camo fatigues	44031D	7.32	.1515	2.38	4.715	.8625	.4450
4 100% wool pants	823J (CL5)	9.92	.368	2.26	3.57	.7600	.5110
5 50/50 poly/ct pants	43795	6.91	.265	2.23	2.92	.4885	.3735
6 65/35 poly/ct durapress	43992A	4.70	.0875	2.25	3.83	.4175	.2810
7 >47/x poly/ct pocket liner	43718C	4.25	—	2.12	6.11	.3425	.3320
8 55/45 poly/wl pants	21115K (CL3)	10.2	.4405	2.11	3.70	.7565	.6050
9 100% nylon lining	21852F	1.80	.072	2.09	3.47	.1240	.1020
10 100% cot poplin,camo	43468F	6.17	.201	2.43	2.59	.5015	.3685
11 55/45 poly/wl pants	823J (CL3)	6.56	.1985	2.46	8.79	.6085	.4260
12 50/50 poly/ct pants	43791B	7.55	.2175	2.27	3.72	.6275	.4805

TABLE II. Ply Separation Performance

* Force is in linear spring scale units.

DESCRIPTION	MIL SPEC MIl-C-	Clupicker Mechanical Settings & Efficiency					
		GAP(in)	Ave Force	Range	%EFF		
1 55/45 poly/wl pants	21115K (CL5)	.023	20.5	7-34	100		
2 65/35 poly/ct shirting	43992A	.011	20.5	7-34	100		
3 50/50 cot/nyl camo fatigues	44031D	.023	20.5	7-34	100		
4 100% wool pants	823J (CL5)	.032	20.5	7-34	100		
5 50/50 poly/ct pants	43798	.021	25.0	16-34	100		
6 65/35 poly/ct durapress	43992A	.016	20.5	7-34	100		
7 >47/x poly/ct pocket liner	43718C	.020	23.5	16-31	100		
8 55/45 poly/wl pants	21115K (CL3)	.036	20.5	7-34	100		
9 100% nylon lining	21852F	.005	13.4	7-20	99.7		
10 100% cot poplin,camo	43468F	.018	24.0	14-34	99.5		
11 55/45 poly/wl pants	823J (CL3)	.023	20.5	7-34	100		
12 50/50 poly/ct pants	43791B	.025	20.5	7-34	100		

Appendix I.

Operator's Manual of the Turn & Divide Module

Operator's Manual

for the

Turn & Divide Module

written by

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INTRODUCTION

The purpose of this instruction manual is to provide the operator of the Turn and Divide with the basic information necessary to set up the machine for the intended use and run the machine in an average day to day operation.

The setup of this manual will cover the following in operating order:

Page #

MACHINE DIAGRAM AND DESCRIPTION

The figures listed on pages 2-4 are included to clarify certain terminology that refers to areas or parts on the machine.

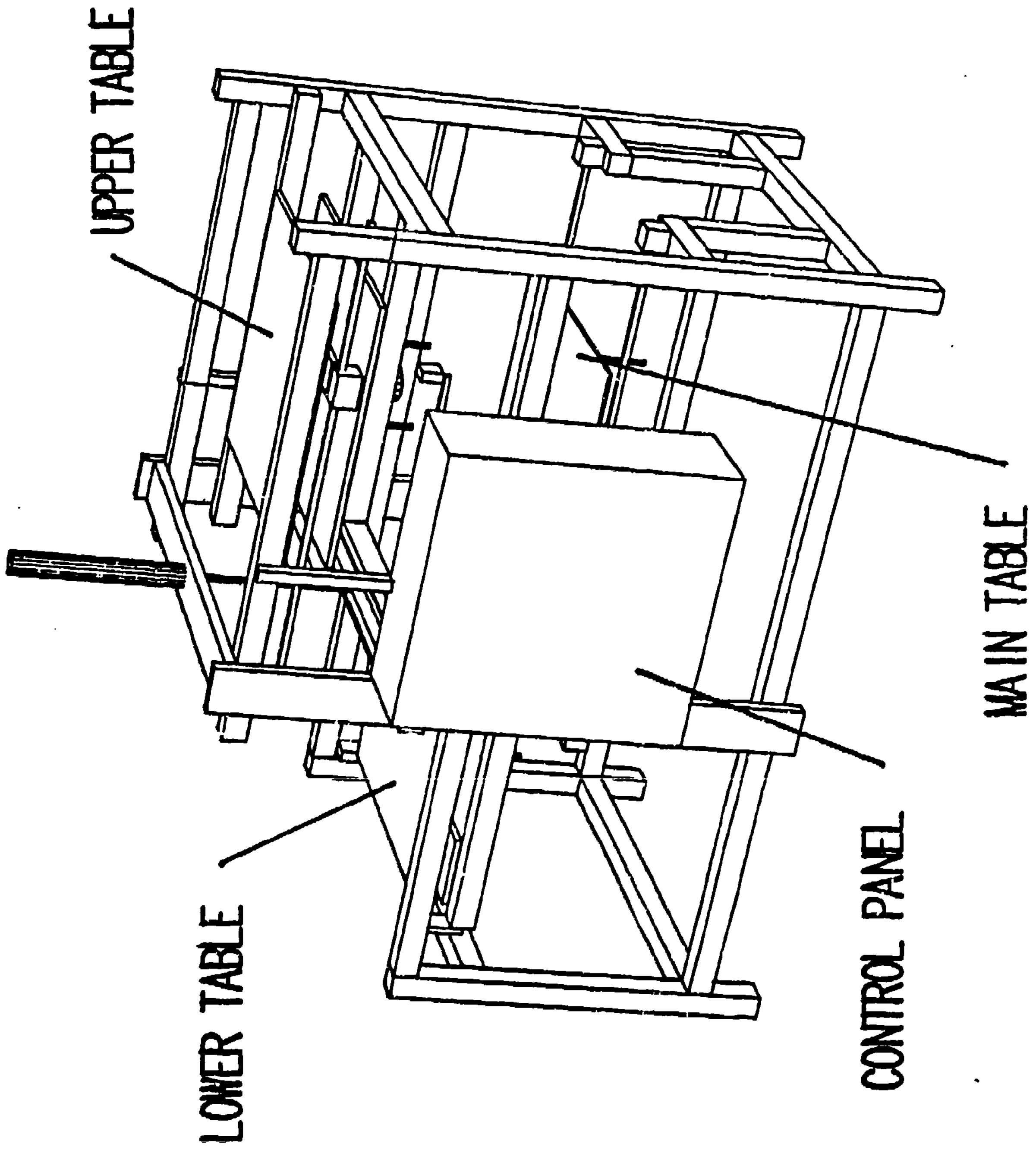

FIG. #1

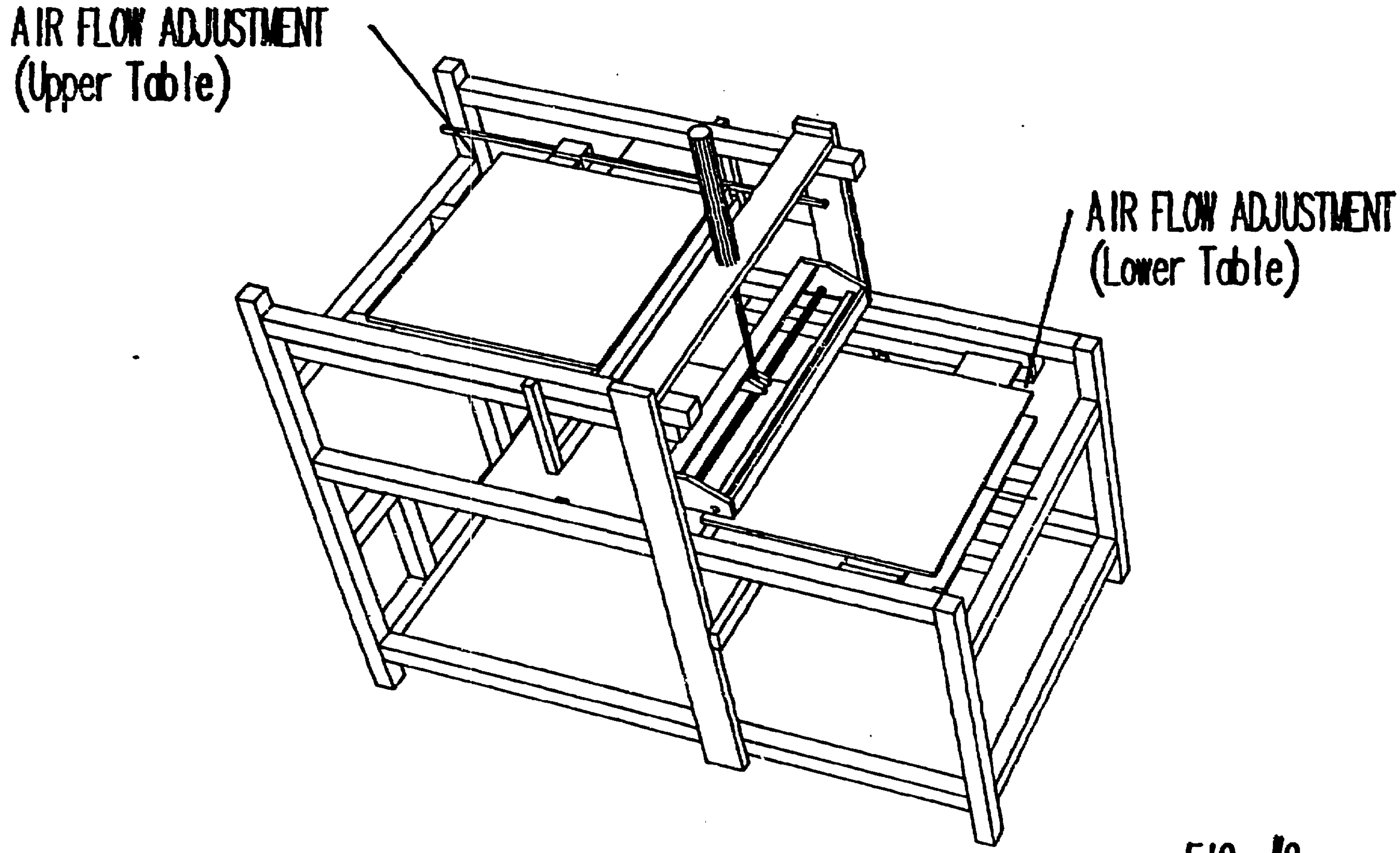
AIR FLOW ADJUSTMENT
(Upper Table)
AIR FLOW ADJUSTMENT
(Lower Table)

FIG. #2

CONTROL PANEL DESCRIPTION

The control panel is where all major operating functions will be controlled and the status of the machine will be monitored. (See Figure #1, p. 3 for location) The panel is made up of switches, buttons, and lights. The switches and buttons will be used to operate the machine. The lights represent stages of operation or reasons why the machine is down. The following is a description of each element on the panel and its purpose:

Lower Cycle *(blue light)* - Lit when the ply separation unit's present operation is to pick and release onto the lower table.

Upper Cycle *(blue light)* - Lit when the ply separation unit's present operation is to pick and release onto the upper table.

Unload *(blue light)* - Lit when the upper and lower tables have moved inward and are in the unload position.

Manual *(blue light)* - Lit when the machine is switched to the manual mode.

Auto *(blue light)* - Lit when the machine is switched to the automatic (run) mode.

Start *(red button)* - Depress to start the operation of the machine (auto mode only).

Reset *(black button)* - Depress to reset any red "error" lights before starting the machine to resume operation.

Run/Unload *(switch)* - "Run" mode to operate the machine. "Unload" mode (after stopping machine and in "manual") to unload the upper and lower tables. (When placed into the "unload" mode the tables will abruptly move to the inside of the machine and when put back into "run" mode they will move back at the same rate.)

Manual/Off/Auto *(switch)* - "Manual" mode to unload upper/lower tables and to manually move parts of the machine (tables and pickers, to be discussed later). "Off" mode to cease automatic functions but not to stop the cycle operation. "Auto" mode for operation of the machine.

Cycle Repeat On/Off *(switch)* - In "On" mode and "Auto" the machine will continue to cycle until the stack on the main table has been finished or an error occurs. In the "Off" mode and "auto" mode the machine will run one cycle (lower table then to upper table) then will resume position at main table and stop.

CONTROL PANEL DESCRIPTION (continued)

Picker Arm Position *(red light)* - Lit when pickers in lowered position ready to separate top ply.

Picker Frame Position *(red light)* - Lit when picker frame moving upward and in upper table position.

Pickers Jammed *(red error light)* - Lit when sensor behind pickers has been tripped. Usually means ply has become trapped in the picker area somehow.

Pickers Did Not Pick *(red error light)* - Lit when ply not picked up from main table. In the case of two pickers, one failing will trigger sensor.

Emergency Stop *(large red stop)* - Pull out to operate the machine. Depress in case of absolute emergency. (Upper and lower tables do not immediately stop, will return to run position)

Picker Pick *(black button)* - Depress when in "Manual" mode to activate pickers into the down and pick position. Release to bring the pickers back to the original up position. (Will not release ply if in the picker wheel)

Picker Release *(black button)* - Depress when in "Manual" mode to release ply in picker wheel. To be used in conjunction with "Picker Pick" in "Manual" mode.

Main Table Down *(black button)* - Depress when in "Manual" mode to lower main table.

Raise Tables *(black button)* - Depress when in "Manual" mode to raise all three tables. (main, lower, and upper)

PRIMARY MACHINE SET UP

The primary machine set up involves steps to be taken to prepare the machine for loading and operation after a period of shut down.

1.) Supply power to the machine through whatever electrical configuration that is being used. Pull the "Emergency Stop" out to its furthest position.

2.) Check air pressure gauge (under lower table). Pressure should be maintained close to 68 psi.

3.) Switch control panel to "Manual" and "Unload" and check upper and lower tables for any samples not unloaded previously.

4.) Switch control panel back to "Run" and "Manual" and proceed with further operating instructions. (Tables will move back to run position)

PLY SEPARATION CALIBRATION

The ply separation calibration involves setting up the Cluett, Peabody "Clupicker" for the material that will be separated. These steps correspond to the "Clupickers" after modification with a spring scale. The picker should be set up in the order of steps given. Deviations from the Jet Sew manual will be discussed below, while those procedures followed exactly will be referenced by page number.

Tools needed:

- $^{3}/_{64}$ inch allen wrench
- Gap gauge
- Micrometer

NOTE: Figure and part numbers refer to original Jet Sew manual

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Adjustment of Shoe Gap

The adjustment of the shoe (number 8, FIGURE 13) has proven through testing to be the most important element in ply separation efficiency. This involves adjusting the gap of the shoe properly according to the fabric being used. This is an operator adjustment and should be done each time a new fabric is introduced to the machine.

A sample of the fabric should be taken and folded as to double the thickness (two plies). With the micrometer (or other measuring device), using hand force enough to fully compress the two plies, measure the thickness. The gap that the shoe should be set at will be this measured thickness. Record this gap setting for future set up for this fabric.

Example:

If the fabric is folded and the two ply thickness is measured to be $^{18}/_{1000}$ inches, the shoe gap will be set at $^{18}/_{1000}$ inches.

To adjust the gap of the shoe, the allen wrench must be used to loosen the adjusting screw (point "D",FIGURE 10). With the correct gap selected from the gap gauge, place the gauge in between the shoe and picker wheel (number 11, FIGURE 11), slide the shoe up against the gauge and retighten the adjusting screw.

PLY SEPARATION (continued)

This adjustment is crucial to the performance of the picker system. If the shoe is too close to the picking wheel teeth, certain fabrics may be marked and pick efficiency is reduced. If the shoe is too far from the picker wheel, faulty "cast-off" (material not releasing from the picking head) can occur and pick efficiency is again reduced.

Pressure of the Picking Wheel

The picking wheel is driven downward by the compression of a spring (number 45, FIGURE 10). This spring force is also important in the picker efficiency. When the shoe gap adjustment is made properly, the operating range of the spring force tends to be fairly large.

The optimum pressure of the picking head against the top ply of fabric will vary with fabric characteristics. The finer and lighter a fabric is, less spring force will be required. In the same manner the stiffer and heavier a fabric is, more spring force will be required.

This procedure involves manually operating the pickers with the fabric to be used to locate a minimum and maximum operating spring force range. To find the range, load a stack of fabric onto the main table (see "Table Set up"). Set the control panel to "Manual" and "Run", raise the main table until it stops (using the "Raise Tables" button). Set the spring to its minimum position by turning the knurled nuts (B, FIGURE 10) back away from the picker shoe apparatus. Depress the "Picker Pick" button and then release it. To release the picked ply depress the "Pickers Release" button and clear that sample from the table. If both the pickers picked with no difficulty, this is your minimum value for spring force. To find the maximum spring force value, tighten the knurled nuts towards the shoe apparatus and double repeat the manual pick test until the pickers ~~do not~~ pick or no more adjustment is available. This is your maximum spring force value.

The optimum spring force setting will be the average (or in the middle) of the minimum and maximum settings. Record this setting for future set up with this fabric. The springs should be adjusted to this setting and tightened with the double nut until further adjustment is necessary.

For extremely limp and extraordinarily delicate fabric the speed at which the picking head drops may need adjusting. See Jet Sew manual, page 2.

TABLE SET UP

The table set up involves the three tables: main, lower, and upper (See Figure #1, p. 3). They must either be loaded with the fabric stack or adjusted for placement of separated plies.

> *NOTE: Figure and part numbers refer to original Jet Sew manual*

The main table must be loaded with a fabric stack before the operation can proceed. Lower the table, using the "Main Table Down" button, far enough below the "Hold Down Fingers" (E, FIGURE 11) to fit the fabric stack underneath. Release the table by moving the "Table Release" switch to the unload position (up position). Pull out the table slowly until it stops. Load the fabric underneath the "Hold Down Fingers" evenly distributed on each side. Push the table back into its original position and move the "Table Release" to the run position (down position).

The upper and lower tables must be adjusted for ply placement. This can only be done after one cycle (upper and lower) has been run on the machine. With the control panel in the "Auto" mode and "Cycle Repeat" off, depress the "Reset" then "Start" button. The machine will run one complete cycle. Pay attention to the placement of the plies onto the tables in relation to the magnets set up on the surface. Adjust these magnets to fit around the fabric and in strategic spots to "catch" the ply as it is placed onto the tables.

Another adjustment involved with the tables is the raising and lowering of all three. The main table will raise itself automatically to the proper height and maintain it while in the "Auto" mode. The only time it will require manual adjustment will be to lower it for loading.

The upper and lower tables must be raised before start up by depressing the "Raise Tables" button. They will stop when they are at their appropriate height. At this time, release the "Raise Tables" button. This allows for proper placement of the separated ply on its new stack.

Finally, a third adjustment of the table movement speed may be required on the upper and lower tables. This adjustment may be necessary when using an extremely light weight or slick (relative to the table surface) fabric. Air flow valve adjustments increase or decrease the capacity of air passing through the valve, therefore slowing down or speeding up the table movement. (See Figure #2, p. 4 this manual for locations) These adjustments are made with a screwdriver inserted into the adjusting screw and turned clockwise to restrict air flow and slow the table down or counter clockwise to increase air flow and speed the table up.

OPERATION

The operation of the machine is possible after the picker shoe gap, spring force, and three tables have been properly adjusted. This includes loading the main table with the fabric to be processed. (see Table Set Up)

To begin the operation, switch the control panel to "Auto", "Cycle Repeat On", and "Run". The blue "Auto" light should appear. If it does not, press the "Reset" button and then the "Start" button to begin the operation. In the case that a red error light is on, correct the problem which caused the error, press the "Reset" button, and then the "Start" button to begin the operation. The machine will now cycle automatically until it is stopped manually by the operator or a problem arises and an error light appears.

To stop the machine manually, switch the "Cycle Repeat" to the OFF position. The machine will finish the next consecutive upper cycle and then stop.

If the machine stops and an error light appears, the machine has run into a problem and will require operator assistance. There are two error lights which this could involve:

Pickers Jammed - In this case, the sensor behind the pickers has been signaled that the ply that was lifted from the stack has dropped from one or both of the pickers before it was placed on its appropriate table. The ply should be removed, the machine reset and restarted.

Pickers Did Not Pick - In this case, there are two possibilities. The stack on the main table has been finished and it should be reloaded or the one or both of the pickers failed to pick the top ply from the stack on the main table. The top ply should be checked for any disturbance from its original position, the machine reset and restarted.

DEFENSE LOGISTICS AGENCY
TURN AND DIVIDE

(INSTALLATION MANUAL)

~~Appendix XI~~

INTRODUCTION

The purpose of this manual is to provide a basis for the technicians initial installation of the Turn and Divide. This is not intended for the operators everyday use.

Initially, before proceeding with these instructions, inspect the machine for any damage and tighten all fasteners.

The setup of this manual will cover the following in sequential order:

ELECTRICAL AND PNEUMATIC REQUIREMENTS

The setup requirements are as follows:

- 110 volt AC electrical source
- 90 psig minimum compressed air source

DEFAULT MEASUREMENTS

Correct adjustment of this machine is crucial to its performance. Assuming that different adjustments will be made on each individual machine after installation, it is a good idea to measure and document the delivered settings. This insures that a default is always known.

Scribe the positions of sensors on the upper and lower tables and measure the positions of other adjustments to a relative position.

PLY SEPARATION SET UP

The ply separation unit includes the Cluett, Peabody "Clupicker" and the "Hold Down Finger Assembly" (HDFA). Deviations from the Jet Sew manual will be discussed below, while those procedures followed exactly will be referenced by page number.

NOTE: Figure and part numbers refer to original Jet Sew manual

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Adjustment of the HDFA

The hold down finger (Letter E, Figure 11) serves three important functions; that of sensing and controlling the height of the stack, to hold down unwanted plies of material when the picking head comes up, and to hold the remaining stack of material from becoming disordered during the next element of the cycle. Adjustment is not necessary for a wide range of materials; but in the case it is, ***refer to pages # 5-6.***

Alignment of the HDFA

The alignment of the HDFA with respect to the Clupicker wheel used in preparation of this manual differs from that of the Jet Sew manual. ***Refer to Figure 11 (lower half of page).*** The recommended alignment found to be most efficient was where the Hold Down Finger was directly in line with the Clupicker wheel.

Placement of HDFA and Pickers

For different size and shape fabric pieces to be run in the machine, lateral position adjustment of the HDFA and the Clupickers may be necessary. ***Refer to Figure # 11 (top half of page) and "Lateral Picker Alignment" section.***

CARE AND MAINTENANCE

Ply Separation Unit:

Refer to "Preventive Maintenance" section of Jet Sew manual.

Turn and Divide:

Daily:

- Clean upper and lower tables of accumulated debris.
- Empty water trap in air line.

Weekly:

- Lubricate air lines (if not equipped with automatic oiler).
- Lubricate table slide rails.
- Inspect sensor operation.

Monthly:

- Check and retighten all fasteners on machine.

Appendix II. Fabric Specifications

Reference Number 1
Description: Polyester/Wool cloth, Tropical, Blue SH 1578.
Military Specification: MIL-C-21115K, 18 Dec 87, Type III, Class 3.
National Stock Number: 8305-01-057-7291
Weave: plain weave.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 55 to 60 percent polyester and remaining percentage wool, blended and spun into a 2-ply yarn. Polyester shall have a minimum of 3 inches average fiber length. The wool shall be fleece or pulled or both of not less than grade 64's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.1	6.75	50	44	100	80	---	---

Reference Number 2
Description: Polyester/Cotton cloth, Broadcloth, AG-415
Military Specification: MIL-C-43992A, 10 May 85, Class 5.
National Stock Number: 8305-01-074-1843
Construction: End and end construction. Warp yarns are alternate dyed and white. Filling yarns are all white.
Weave: plain weave
Width: as specified in order, test fabric was 45" wide.
Length: not less than 40 yard continuous lengths.
Typical Yarn Counts: 37's warp and filling, 40's warp and filling, 40's warp and 37's filling
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
3.1	3.8	97	62	95	50	4.5	2.5

Reference Number 3
Description: Cotton/Nylon cloth, Woodland Camouflage (printed).
Military Specification: MIL-C-44031D, 22 Aug 89, Class 1.
National Stock Number: 8305-01-087-1329
Weave: 2 up and 1 down left hand twill Width: as specified in order, test fabric was 60" wide.
Length: not less than 40 yard continuous lengths.
Yarn: 50/50 percent cotton/nylon based on the dry weight of the desized cloth. Nylon shall be high tenacity, semi-dull staple with a nominal cut length of 1.5 inches. The cross sections shall be round with a nominal denier of 2.25 to 2.5. Cotton shall be carded.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.8	---	86	54	200	125	11	8

Air Permeability: 25.0 ft3/min/ft2

Fabric Specifications

Reference Number 4
Description: Wool cloth, Serge, Blue SH 3346.
Military Specification: MIL-C-823J, 21 Dec 83, Class 5.
National Stock Number: 8305-00-350-5640
Weave: 2 up 2 down, 4 harness right twill.
Width: as specified in order, test fabric was 57" wide.
Length: not less than 50 yard continuous lengths.
Yarn: Wool, 62's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
15	---	70	58	100	80	--	---

Reference Number 5
Description: Polyester/Cotton cloth, Durable press.
Military Specification: MIL-C-43791B, 13 Feb 79, Type 2, Class 1.
National Stock Number: 8305-01-033-4410
Weave: 2 up 1 down left hand twill.
Width: as specified in order, test fabric was 45" wide.
Length: as specified in order.
Yarn: 50/50 percent polyester/cotton based on the dry weight of the dyed cloth before treatment.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.8	7.8	104	50	170	80	5.0	3.0

Reference Number 6
Description: Polyester/Cotton cloth, Durapress.
Military Specification: MIL-C-43992A, 10 May 85, Class 2.
National Stock Number: Unknown
Weave: plain weave
Width: as specified in order, test fabric was 60" wide.
Length: not less than 40 yard continuous lengths.
Yarn: 65/35 polyester/cotton.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
3.5	4.0	100	64	70	52	3.0	3.0

Fabric Specifications

Reference Number 7
Description: Polyester/Cotton cloth, for pockets.
Military Specification: MIL-C-43718C, 17 Jun 88, Class 1.
National Stock Number: 8305-01-062-7490
Weave: 2 up and 1 down twill
Width: as specified in order, test fabric was 45" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 47 to 100 percent polyester and remaining percentage cotton or rayon. When 100 percent polyester is used the yarn shall be staple or texturized filament polyester.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
3.7	4.9	73	46	72	55	---	---

Reference Number 8
Description: Polyester/Wool cloth, Tropical, Blue SH 3346.
Military Specification: MIL-C-21115K, 18 Dec 87, Type III, Class 3.
National Stock Number: 8305-00-150-2246
Weave: plain weave.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 55 to 60 percent polyester and remaining percentage wool, blended and spun into a 2-ply yarn. Polyester shall have a minimum of 3 inches average fiber length. The wool shall be fleece or pulled or both of not less than grade 64's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.1	6.75	50	44	100	80	---	---

Reference Number 9
Description: Nylon cloth, Taffeta.
Military Specification: MIL-C-21852F, 6 Feb 89, Type II.
National Stock Number: Unknown
Weave: plain weave.
Width: as specified in order, test fabric was 45" wide.
Length: not less than 40 yard continuous lengths.
Yarn: Nylon prepared from hexamethylene diamine and adipic acid with a minimum melting point of 472o F. The yarn shall be multifilament nominal 50 denier (5.6 Tex) for the warp and nominal 70 denier (7.6 Tex) for the filling.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
1.5	---	95	65	75	75	4.0	6.0

Air Permeability: 70 ft3/min/ft2.

Fabric Specifications

Reference Number 10
Description: Cotton cloth, Camouflage Pattern, Wind Resistant Poplin, Ripstock.
Military Specification: MIL-C-43468F, 26 Jul 88, Type III.
National Stock Number: 8305-01-167-8403
Weave: The weave shall have reinforcement ribs in both the warp and the filling directions forming a uniform pattern. The warp repeat shall be 2 ends weaving as one in a plain weave manner with 23 ends weaving plain weave. The filling repeat shall be 2 picks weaving as one in the plain manner with 12 picks weaving plain weave.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 40 yard continuous lengths.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
5.7	7.0	104	52	110	68	4.0	4.0

Air Permeability: 18.0 ft3/min/ft2.

Reference Number 11
Description: Polyester/Wool cloth, Serge, Blue SH 3346.
Military Specification: MIL-C-823J, 21 Dec 83, Type III, Class 3.
National Stock Number: 8305-00-350-5657
Weave: 2 up 2 down, 4 harness right twill.
Width: as specified in order, test fabric was 59" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 55 to 60 percent polyester and remaining percentage wool, blended and spun into a 2-ply yarn. Polyester shall have a minimum of 3 inches average fiber length. The wool shall be fleece or pulled or both of not less than grade 64's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
11.3	---	78	68	140	125	---	---

Reference Number 12
Description: Polyester/Cotton cloth, AG 344.
Military Specification: MIL-C-43791B, 13 Feb 79, Class 1.
National Stock Number: 8305-01-121-7503
Weave: 2up 1 down, right hand twill.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 50/50 polyester/cotton based on dry weight of dyed cloth before treatment. Warp yarns shall be two ply, filling yarns shall be singles.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.8	7.8	104	50	170	80	5.0	3.0

A Study of the

Influence of Vacuum Compression on the Attractive Force Between Plies of Cut Parts

by

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February 5, 1990

ABSTRACT

As part of the Defense Logistics Agency's contract titled, "Manufacturing Technology for Apparel Automation," a study was conducted to quantify the attractive force between plies of fabric using a variety of factors. These factors are listed as follows: 1) type of fabric (12 military apparel fabrics), 2) type of compression (vacuum compressed versus restacked), and 3) type of contact (face-to-face or back-to-back).

The results of this study have quantified the practical knowledge that there is more attraction between plies of fabric that have been vacuum compressed than those that have been restacked. After initial separation, the attractive force or pressure is reduced by an average of 85%, thus making the separation and feeding of restacked parts much easier. A comparison of face-to-face and back-to-back contact showed that there was over a 20% difference between types of contact for half of the fabrics. This fact must be considered when optimizing the mechanical parameters of the ply separation system. The magnitudes of the attractive force or pressure were similar for ten of the twelve fabrics tested, thus increasing the chance of successful optimization. But the other two were much different. This fact is important because the mechanical system must be designed to handle the extremes in the class of fabrics used in production.

Introduction

Ply separation is an important operation in apparel manufacturing. Efforts to automate this operation have been difficult for a number of reasons. One of those reasons is the attractive force between plies of fabric after they have been cut. These ply-to-ply attraction forces resist separation and can create inefficient operation of an automated ply separation system.

In most apparel manufacturing processes, fabric is arranged in multiple layers before it is to be cut into garment parts. These layers are often arranged in manner such that the front side of one layer contacts the front side of the next layer. This is called face-to-face spreading as shown in Figure 1. In this type of spreading the back side of layers also contact each other. Consequently, the attraction forces may be different between face-to-face and back-to-back contact regions.

The fabric is now ready for cutting. The cutting operation is either manual or automatic. The automated cutting operation is believed to create the highest attraction forces and is described below. The fabric spread is covered with plastic and is compressed under a vacuum pressure of approximately 3-5 inches of mercury. The fabric is then cut into garment parts. The stacks of garment parts are ready to be separated into single plies. After initial separation, single plies are often restacked for subsequent operations.

The purpose of this study is to determine the influence of vacuum compression on attraction forces between fabric plies. The influence of face-to-face and back-to-back configurations will be quantified using typical military fabrics.

Attraction Force Measurement

The experiment involves measuring the ply-to-ply attractive forces associated with the removal of the top ply in a fabric stack. Since no ASTM standards exist for the measurement of ply-to-ply force, accurate test equipment had to be built. The equipment is designed to measure the peak force encountered by the top ply as it slides over the one beneath it. The experiment is conducted using twelve military fabrics. In order to verify the statistical significance of the results, fifteen measurements are made on the front and back of each fabric. The equipment and procedures involved in this experiment are described below.

Equipment

The ply to ply force is measured by a Chatillon DFG2-RS232 force gauge that has a maximum capacity of 2 lbs with a resolution of 0.001 lbs. The force gauge is mounted on a Chatillon Model UTSM universal test stand. The test stand controls are adjusted so that the platform moves at a constant speed of 10 inches per minute. The complete experimental apparatus is shown in Figure 2. The experiment also requires a clamping device designed to hold the top fabric ply across its entire width. The clamp must also allow a constant area of contact between the top ply and the fabric stack during each experimental trial. This clamping device is shown in Figure 3.

Fabrics

The twelve military apparel fabrics were tested. They ranged from 1.6 oz. 100% nylon to 15 oz. 100% wool. The fabrics are described in Appendix I. Table I provides a summary of the physical properties of the twelve fabrics.

To prepare the fabric samples for cutting, the cloth was spread on the cutting table in an alternating fashion to obtain 20 plies. The cutting was performed at the $(TC)^2$ National Apparel Technology Center on a Gerber cutter with a vacuum of 4 inches of Mercury. The fabric was cut into 4 by 8 inch stacks. After cutting, the fabrics were ready for testing.

Test Procedures

Multiple measurements of the attractive force were taken for statistical analysis. The five plies of the 20 ply stack were removed. The peak attractive force was measured for each of the next ten plies as they were removed from the stack. Three stacks were selected randomly for each fabric. A total of thirty measurements were taken for each fabric. Of the thirty measurements, fifteen were face-to-face contact and fifteen were back-to-back contact The plies of each fabric were restacked and measured again to quantify the attractive forces after initial separation. The procedure for the experiment is described as follows:

1. Place compressed stack on test platform.
2. Clamp the top fabric ply in the fabric clamping device.
3. Attach the fabric clamp to the force gauge.
4. Zero the force gauge.
5. Using a pencil, hold down the fabric underneath the top layer at the end opposite to the clamp.
6. Now move the platform away from the force gauge.
7. Record the maximum force reading.
8. Remove the fabric from the clamp.
9. Return the platform to the starting position.
10. Repeat steps 2 through 9 ten times for each fabric stack.
11. Perform steps 1 through 11 on three stacks for each fabric.
12. Take a compressed stack of fabric and restack it.
13. Place the stack on the test platform.
14. Perform steps 2 through 12.
15. Repeat steps 1 through 14 for each of the twelve fabrics.

Results and Analysis

A total of sixty measurements of the ply-to-ply attraction force was collected for each fabric. The data are presented in Appendix II. In Appendix II "SIDE1" and "SIDE2" refer to the face-to-face contact and the back-to-back contact. "COMP" and "NCOMP" refer to the stacks that were tested after vacuum compression and those tested after being restacked. The force was measured and is presented in units of pounds.

The effects of compression and type of contact are determined by comparing the average values of the data. The actual force data in Appendix II are averaged according to the comparison being conducted. The average values were divided by the actual area of contact (28 in^2 or 181 cm^2) to obtain a normalized representation of ply-to-ply attraction, which in this case is pressure. The results are summarized in Table II.

The results in Table II quantify the influence of vacuum compression on the attractive force between plies. In every fabric there is at least a 50% increase in attractive force when vacuum compression is used. For this particular set of fabrics, the average increase is 85%. This fact is significant when considering the design of ply separation systems. It is much more difficult to initially separate stacks after vacuum compression than after the plies have been restacked. The ply separation system must be designed to overcome these normal attractive forces as well as special forces created by factors such as edge entanglement or fusion. After the initial attractive bond is broken, special cause forces are eliminated and the normal attractive force is greatly reduced; thus, subsequent ply separation from restacked parts can be performed with less difficulty.

The variation of face-to-face and back-to-back contact was shown not to be significant for half of the fabrics, while the other half varied by at least 20%. Knowledge that this variation is present should be considered when designing or optimizing a ply separation system. The system should be optimized to separate the type of contact with the highest attraction force.

We would [illegible] the ply separation system to have the flexibility to reliably handle a wide variety of fabrics. Table I shows that most of the fabrics have a pressure range between 270 and 394 dynes/cm^2. This seems to be a reasonable variation for the ply separation system to handle. However, there may be fabrics that are outside the normal range of a particular class of fabrics. In

our study, the camouflage twill and the taffeta 100% nylon had average pressures of 705 and 49 dynes/cm^2, respectively. We can see that the inclusion of these fabrics in the group would expand the pressure range by 500%. This variation could make it difficult to design a mechanical system that has the mechanical flexibility to efficiently separate the plies.

We would like to point out that the taffeta 100% nylon had an attractive pressure that was so low (49 dynes/cm^2) that stack integrity was very difficult to maintain. This was a very slick fabric that presents a different problem than the one expected. This problem is not one of the plies sticking together, but one of the stack sliding or moving out of alignment. This must be considered in the mechanical design of the system.

Summary

The results of this study have quantified the practical knowledge that there is more attraction between plies of fabric that have been vacuum compressed than those that have been restacked. After initial separation, the attractive force or pressure is reduced by an average of 85%, thus making the separation and feeding of restacked parts much easier. A comparison of face-to-face and back-to-back contact showed that for half of the fabrics there was over a 20% difference between types of contact for half of the fabrics. This fact must be considered when optimizing the mechanical parameters of the ply separation system. The magnitudes of the attractive pressure were similar for ten of the twelve fabrics tested, thus increasing the chance of successful optimization. But the other two were much different. This fact is important because the mechanical system must be designed to handle the extremes in the class of fabrics used in production.

This study provides additional understanding of the attractive force or pressure between plies of fabric. This study has been limited only to woven, apparel fabrics used by the military; however, the set tested would be representative of the type of range of fabrics that a military contractor might use.

Acknowledgments

We would like to thank the $(TC)^2$ National Apparel Technology Center for providing technical support and use of their facilities in this study. We would also like to thank DPSC for supplying the fabrics and the Defense Logistics Agency for financial support under contract no. DLA 900-87-C-0509.

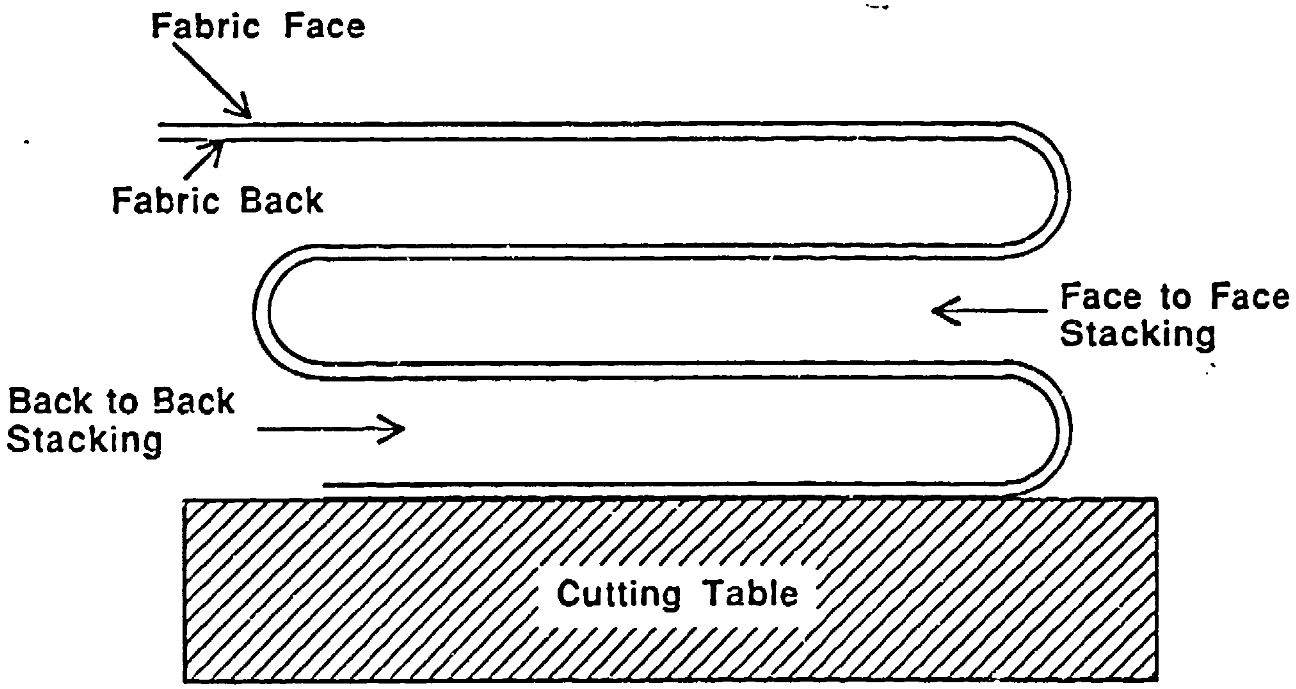


Figure 1. Typical spreading of fabric showing type of contact.

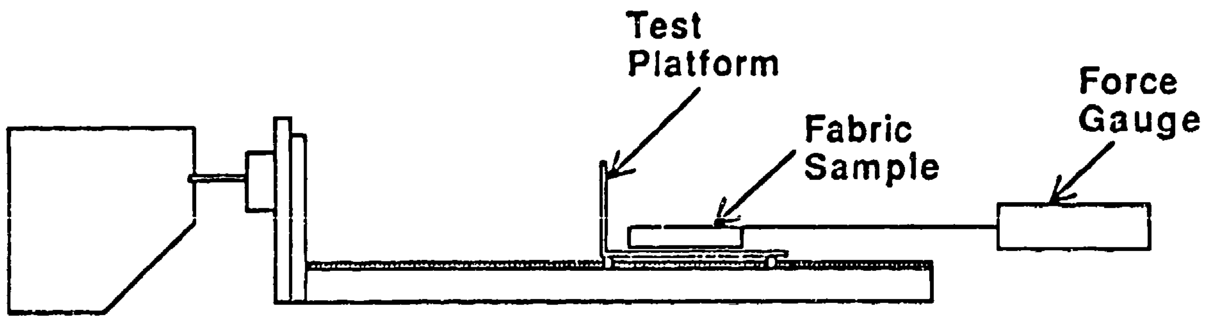


Figure 2. Apparatus for measuring attractive force.

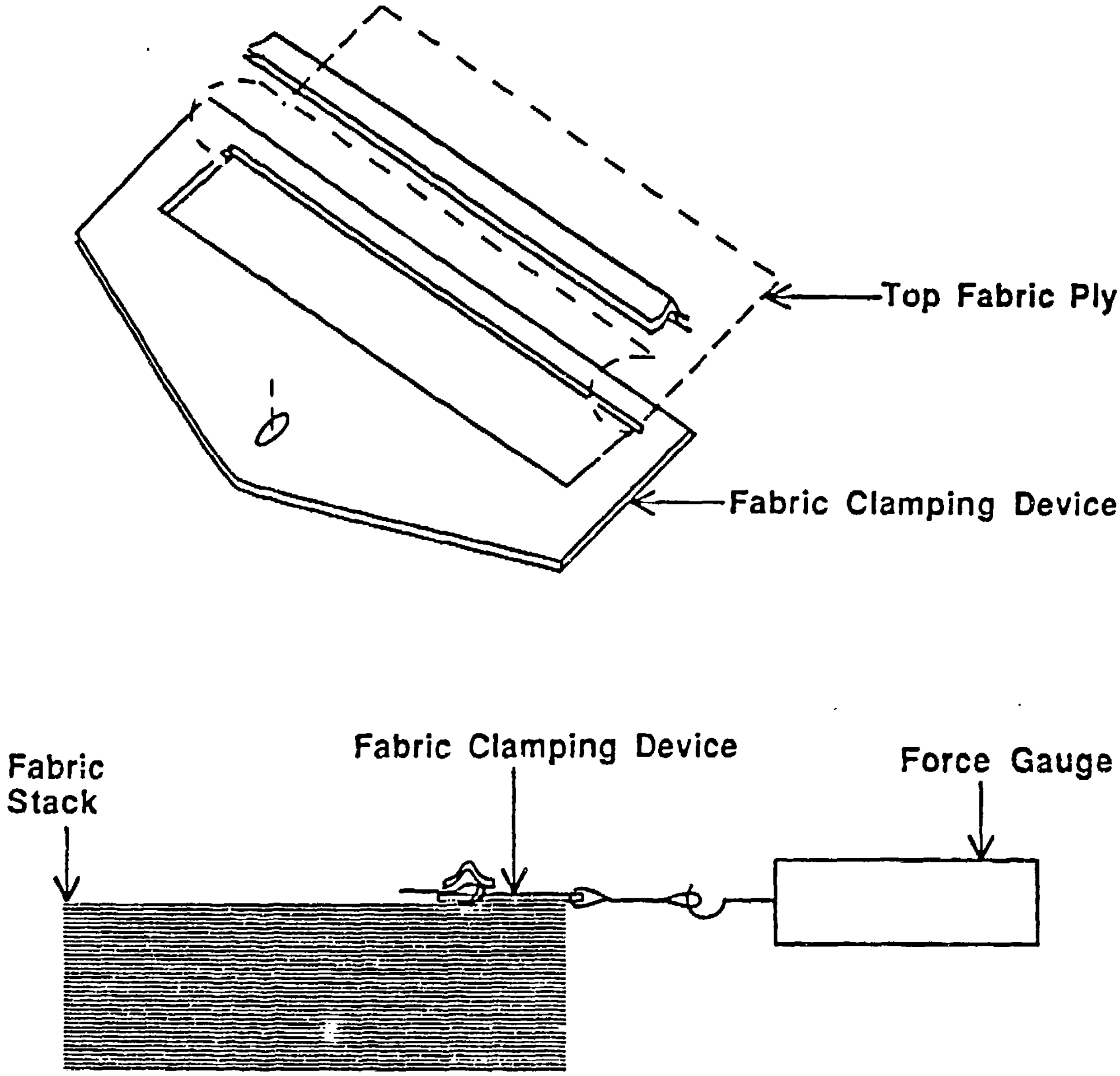


Figure 3: Device for clamping fabric to be tested.

TABLE I. Fabric Physical Properties

DESCRIPTION	MIL SPEC MIL-C-	oz/yd^2 WEIGHT	KAWABATA RIGIDITY	FRICTION	SURFACE	To	Tm
1 55/45 poly/wl pants	21115K (CL5)	6.51	.184	2.22	8.375	.8040	.4300
2 65/35 poly/ct shirting	43992A	3.52	.053	2.19	4.30	.3540	.2175
3 50/50 cot/nyl camo fatigues	44031D	7.32	.1515	2.38	4.715	.6625	.4450
4 100% wool pants	823J (CL5)	9.92	.368	2.26	3.67	.7600	.5110
5 50/50 poly/ct pants	4379B	6.91	.255	2.23	2.92	.4885	.3735
6 65/35 poly/ct durapress	43992A	4.70	.0875	2.25	3.83	.4175	.2810
7 >47/x poly/ct pocket liner	43718C	4.25	—	2.12	6.11	.3425	.3320
8 55/45 poly/wl pants	21115K (CL3)	10.2	.4405	2.11	3.70	.7565	.6060
9 100% nylon lining	21852F	1.80	.072	2.09	3.47	.1240	.1020
10 100% cot poplin,camo	43468F	6.17	.201	2.43	2.59	.5015	.3685
11 55/45 poly/wl pants	823J (CL3)	6.56	.1965	2.46	8.79	.6085	.4260
12 50/50 poly/ct pants	43791B	7.55	.2175	2.27	3.72	.6275	.4805

TABLE II. Ply-to-ply attraction results presented as pressure (dyne/cm2).

DESCRIPTION	MIL SPEC MIL-C-	COMPRESSION			SIDE		
		COMP	NCOMP	%DIF	1	2	%DIF
1 55/45 poly/wl pants	21115K (CL5)	345	222	56	296	271	9
2 65/35 poly/ct shirting	43992A	345	145	133	271	222	22
3 50/50 cot/nyl camo fatigues	44031D	705	394	81	705	394	81
4 100% wool pants	823J (CL5)	370	197	88	296	271	9
5 50/50 poly/ct pants	4379B	271	172	57	222	222	0
6 65/35 poly/ct durapress	43992A	296	148	100	222	222	0
7 >47/x poly/ct pocket liner	43718C	394	197	100	296	296	0
8 55/45 poly/wl pants	21115K (CL3)	394	197	100	320	246	30
9 100% nylon lining	21852F	49	25	100	49	49	0
10 100% cot poplin,camo	43468F	370	222	67	345	271	27
11 55/45 poly/wl pants	823J (CL3)	345	197	75	320	222	44
12 50/50 poly/ct pants	43791B	320	197	63	271	222	22

Appendix I. Fabric Specifications

Reference Number 1
Description: Polyester/Wool cloth, Tropical, Blue SH 1578.
Military Specification: MIL-C-21115K, 18 Dec 87, Type III, Class 3.
National Stock Number: 8305-01-057-7291
Weave: plain weave.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 55 to 60 percent polyester and remaining percentage wool, blended and spun into a 2-ply yarn. Polyester shall have a minimum of 3 inches average fiber length. The wool shall be fleece or pulled or both of not less than grade 64's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.1	6.75	50	44	100	80	---	---

Reference Number 2
Description: Polyester/Cotton cloth, Broadcloth, AG-415
Military Specification: MIL-C-43992A, 10 May 85, Class 5.
National Stock Number: 8305-01-074-1843
Construction: End and end construction. Warp yarns are alternate dyed and white. Filling yarns are all white.
Weave: plain weave
Width: as specified in order, test fabric was 45" wide.
Length: not less than 40 yard continuous lengths.
Typical Yarn Counts: 37's warp and filling, 40's warp and filling, 40's warp and 37's filling
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
3.1	3.8	97	62	95	50	4.5	2.5

Reference Number 3
Description: Cotton/Nylon cloth, Woodland Camouflage (printed).
Military Specification: MIL-C-44031D, 22 Aug 89, Class 1.
National Stock Number: 8305-01-087-1329
Weave: 2 up and 1 down left hand twill
Width: as specified in order, test fabric was 60" wide.
Length: not less than 40 yard continuous lengths.
Yarn: 50/50 percent cotton/nylon based on the dry weight of the desized cloth. Nylon shall be high tenacity, semi-dull staple with a nominal cut length of 1.5 inches. The cross sections shall be round with a nominal denier of 2.25 to 2.5. Cotton shall be carded.
Physical Requirements:

Weight oz/yd2		Yarns per nch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.8	---	86	54	200	125	11	8

Air Permeability: 25.0 ft3/min/ft2

Fabric Specifications

Reference Number 4
Description: Wool cloth, Serge, Blue SH 3346.
Military Specification: MIL-C-823J, 21 Dec 83, Class 5.
National Stock Number: 8305-00-350-5640
Weave: 2 up 2 down, 4 harness right twill.
Width: as specified in order, test fabric was 57" wide.
Length: not less than 50 yard continuous lengths.
Yarn: Wool, 62's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
15	---	70	58	100	80	--	---

Reference Number 5
Description: Polyester/Cotton cloth, Durable press.
Military Specification: MIL-C-43791B, 13 Feb 79, Type 2, Class 1.
National Stock Number: 8305-01-033-4410
Weave: 2 up 1 down left hand twill.
Width: as specified in order, test fabric was 45" wide.
Length: as specified in order.
Yarn: 50/50 percent polyester/cotton based on the dry weight of the dyed cloth before treatment.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.8	7.8	104	50	170	80	5.0	3.0

Reference Number 6
Description: Polyester/Cotton cloth, Durapress.
Military Specification: MIL-C-43992A, 10 May 85, Class 2.
National Stock Number: Unknown
Weave: plain weave
Width: as specified in order, test fabric was 60" wide.
Length: not less than 40 yard continuous lengths.
Yarn: 65/35 polyester/cotton.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
3.5	4.0	100	64	70	52	3.0	3.0

Fabric Specifications

Reference Number 7
Description: Polyester/Cotton cloth, for pockets.
Military Specification: MIL-C-43718C, 17 Jun 88, Class 1.
National Stock Number: 8305-01-062-7490
Weave: 2 up and 1 down twill
Width: as specified in order, test fabric was 45" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 47 to 100 percent polyester and remaining percentage cotton or rayon. When 100 percent polyester is used the yarn shall be staple or texturized filament polyester.
Physical Requirements:

Weight oz/yd2		Yarns per inch		Breaking Strgth pounds (lb)		Tearing Strgth pounds (lb)	
Min	Max	Min		Minimum		Minimum	
		W	F	Warp	Filling	Warp	Filling
3.7	4.9	73	46	72	55	---	---

Reference Number 8
Description: Polyester/Wool cloth, Tropical, Blue SH 3346.
Military Specification: MIL-C-21115K, 18 Dec 87, Type III, Class 3.
National Stock Number: 8305-00-150-2246
Weave: plain weave.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 55 to 60 percent polyester and remaining percentage wool, blended and spun into a 2-ply yarn. Polyester shall have a minimum of 3 inches average fiber length. The wool shall be fleece or pulled or both of not less than grade 64's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch		Breaking Strgth pounds (lb)		Tearing Strgth pounds (lb)	
Min	Max	Min		Minimum		Minimum	
		W	F	Warp	Filling	Warp	Filling
6.1	6.75	50	44	100	80	---	---

Reference Number 9
Description: Nylon cloth, Taffeta.
Military Specification: MIL-C-21852F, 6 Feb 89, Type II.
National Stock Number: Unknown
Weave: plain weave.
Width: as specified in order, test fabric was 45" wide.
Length: not less than 40 yard continuous lengths.
Yarn: Nylon prepared from hexamethylene diamine and adipic acid with a minimum melting point of 472o F. The yarn shall be multifilament nominal 50 denier (5.6 Tex) for the warp and nominal 70 denier (7.6 Tex) for the filling.
Physical Requirements:

Weight oz/yd2		Yarns per inch		Breaking Strgth pounds (lb)		Tearing Strgth pounds (lb)	
Min	Max	Min		Minimum		Minimum	
		W	F	Warp	Filling	Warp	Filling
1.5	---	95	65	75	75	4.0	6.0

Air Permeability: 70 ft3/min/ft2.

Fabric Specifications

Reference Number 10
Description: Cotton cloth, Camouflage Pattern, Wind Resistant Poplin, Ripstock.
Military Specification: MIL-C-43468F, 26 Jul 88, Type III.
National Stock Number: 8305-01-167-8403
Weave: The weave shall have reinforcement ribs in both the warp and the filling directions forming a uniform pattern. The warp repeat shall be 2 ends weaving as one in a plain weave manner with 23 ends weaving plain weave. The filling repeat shall be 2 picks weaving as one in the plain manner with 12 picks weaving plain weave.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 40 yard continuous lengths.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
5.7	7.0	104	52	110	68	4.0	4.0

Air Permeability: 18.0 ft3/min/ft2.

Reference Number 11
Description: Polyester/Wool cloth, Serge, Blue SH 3346.
Military Specification: MIL-C-823J, 21 Dec 83, Type III, Class 3.
National Stock Number: 8305-00-350-5657
Weave: 2 up 2 down, 4 harness right twill.
Width: as specified in order, test fabric was 59" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 55 to 60 percent polyester and remaining percentage wool, blended and spun into a 2-ply yarn. Polyester shall have a minimum of 3 inches average fiber length. The wool shall be fleece or pulled or both of not less than grade 64's U.S. Standard.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
11.3	---	78	68	140	125	---	---

Reference Number 12
Description: Polyester/Cotton cloth, AG 344.
Military Specification: MIL-C-43791B, 13 Feb 79, Class 1.
National Stock Number: 8305-01-121-7503
Weave: 2up 1 down, right hand twill.
Width: as specified in order, test fabric was 60" wide.
Length: not less than 50 yard continuous lengths.
Yarn: 50/50 polyester/cotton based on dry weight of dyed cloth before treatment. Warp yarns shall be two ply, filling yarns shall be singles.
Physical Requirements:

Weight oz/yd2		Yarns per inch Min		Breaking Strgth pounds (lb) Minimum		Tearing Strgth pounds (lb) Minimum	
Min	Max	W	F	Warp	Filling	Warp	Filling
6.8	7.8	104	50	170	80	5.0	3.0

Appendix II. Attractive Force Data

Measured ply-to-ply attraction force (units in pounds).

FABRIC 1: 55/45 poly/ct pants

		SIDE1	SIDE2
COMP.	1.	0.119	0.104
	2.	0.142	0.120
	3.	0.127	0.115
	4.	0.144	0.139
	5.	0.149	0.127
	6.	0.111	0.097
	7.	0.122	0.089
	8.	0.135	0.132
	9.	0.155	0.138
	10.	0.235	0.141
	11.	0.167	0.134
	12.	0.173	0.163
	13.	0.185	0.131
	14.	0.174	0.149
	15.	0.167	0.181
NCOMP.	1.	0.069	0.090
	2.	0.084	0.082
	3.	0.103	0.090
	4.	0.091	0.103
	5.	0.111	0.111
	6.	0.082	0.079
	7.	0.092	0.089
	8.	0.106	0.085
	9.	0.099	0.089
	10.	0.097	0.073
	11.	0.085	0.082
	12.	0.088	0.083
	13.	0.083	0.088
	14.	0.089	0.091
	15.	0.103	0.097

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0943

FABRIC 2: 65/35 poly/cot shirting

		SIDE1	SIDE2
COMP.	1.	0.147	0.121
	2.	0.154	0.111
	3.	0.151	0.106
	4.	0.150	0.141
	5.	0.185	0.127
	6.	0.150	0.125
	7.	0.165	0.132
	8.	0.167	0.130
	9.	0.172	0.122
	10.	0.164	0.143
	11.	0.109	0.092
	12.	0.125	0.091
	13.	0.117	0.112
	14.	0.136	0.086
	15.	0.143	0.115
NCOMP.	1.	0.073	0.064
	2.	0.067	0.063
	3.	0.066	0.054
	4.	0.057	0.065
	5.	0.054	0.058
	6.	0.073	0.063
	7.	0.067	0.053
	8.	0.069	0.057
	9.	0.072	0.067
	10.	0.062	0.068
	11.	0.055	0.052
	12.	0.071	0.057
	13.	0.053	0.052
	14.	0.052	0.049
	15.	0.051	0.062

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0001

Measured ply-to-ply attraction force (units in pounds).
(continued)

FABRIC 3: 50/50 cot/nyl camo fatigues

		SIDE1	SIDE2
COMP.	1.	0.387	0.175
	2.	0.379	0.219
	3.	0.3[illegible]	0.212
	4.	0.428	0.216
	5.	0.403	0.227
	6.	0.367	0.201
	7.	0.400	0.250
	8.	0.393	0.231
	9.	0.389	0.265
	10.	0.362	0.239
	11.	0.317	0.142
	12.	0.351	0.209
	13.	0.361	0.155
	14.	0.345	0.119
	15.	0.410	0.098
NCOMP.	1.	0.151	0.110
	2.	0.140	0.112
	3.	0.189	0.108
	4.	0.181	0.143
	5.	0.163	0.143
	6.	0.170	0.093
	7.	0.221	0.163
	8.	0.236	0.115
	9.	0.207	0.109
	10.	0.210	0.133
	11.	0.152	0.087
	12.	0.201	0.115
	13.	0.177	0.099
	14.	0.195	0.111
	15.	0.191	0.125

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0001

FABRIC 4: 100% wool pants

		SIDE1	SIDE2
COMP.	1.	0.102	0.111
	2.	0.103	0.117
	3.	0.125	0.113
	4.	0.140	0.125
	5.	0.127	0.136
	6.	0.171	0.137
	7.	0.232	0.185
	8.	0.213	0.181
	9.	0.211	0.179
	10.	0.235	0.126
	11.	0.119	0.096
	12.	0.160	0.113
	13.	0.142	0.146
	14.	0.185	0.148
	15.	0.191	0.137
NCOMP.	1.	0.082	0.081
	2.	0.084	0.087
	3.	0.092	0.088
	4.	0.098	0.089
	5.	0.100	0.093
	6.	0.078	0.067
	7.	0.075	0.066
	8.	0.077	0.069
	9.	0.067	0.071
	10.	0.083	0.073
	11.	0.076	0.067
	12.	0.083	0.075
	13.	0.081	0.079
	14.	0.089	0.076
	15.	0.072	0.081

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0285

Measured ply-to-ply attraction force (units in pounds).
(continued)

FABRIC 5: 50/50 poly/cot pants

		SIDE1	SIDE2
COMP.	1.	0.097	0.084
	2.	0.119	0.101
	3.	0.119	0.109
	4.	0.114	0.103
	5.	0.106	0.115
	6.	0.109	0.119
	7.	0.130	0.095
	8.	0.108	0.102
	9.	0.129	0.115
	10.	0.089	0.136
	11.	0.112	0.107
	12.	0.119	0.135
	13.	0.116	0.123
	14.	0.123	0.112
	15.	0.131	0.130
NCOMP.	1.	0.064	0.082
	2.	0.075	0.074
	3.	0.085	0.075
	4.	0.091	0.073
	5.	0.069	0.077
	6.	0.073	0.072
	7.	0.061	0.071
	8.	0.070	0.067
	9.	0.065	0.061
	10.	0.066	0.067
	11.	0.079	0.054
	12.	0.076	0.069
	13.	0.061	0.057
	14.	0.065	0.057
	15.	0.061	0.051

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.3103

FABRIC 6: 65/35 poly/cot durapress

		SIDE1	SIDE2
COMP.	1.	0.089	0.073
	2.	0.099	0.075
	3.	0.127	0.107
	4.	0.129	0.106
	5.	0.142	0.119
	6.	0.134	0.111
	7.	0.134	0.113
	8.	0.143	0.139
	9.	0.163	0.162
	10.	0.171	0.131
	11.	0.081	0.084
	12.	0.092	0.081
	13.	0.109	0.103
	14.	0.119	0.131
	15.	0.126	0.105
NCOMP.	1.	0.063	0.057
	2.	0.063	0.054
	3.	0.065	0.058
	4.	0.059	0.062
	5.	0.062	0.060
	6.	0.067	0.067
	7.	0.065	0.059
	8.	0.073	0.055
	9.	0.071	0.055
	10.	0.069	0.058
	11.	0.061	0.055
	12.	0.058	0.055
	13.	0.064	0.055
	14.	0.064	0.061
	15.	0.059	0.055

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0300

Measured ply-to-ply attraction force (units in pounds). (continued)

FABRIC 7: >47/x poly/cot pocket liner

		SIDE1	SIDE2
COMP.	1.	0.140	0.115
	2.	0.136	0.100
	3.	0.133	0.141
	4.	0.150	0.146
	5.	0.157	0.130
	6.	0.161	0.157
	7.	0.151	0.147
	8.	0.177	0.163
	9.	0.155	0.204
	10.	0.187	0.176
	11.	0.143	0.177
	12.	0.153	0.135
	13.	0.173	0.182
	14.	0.179	0.142
	15.	0.174	0.149
NCOMP.	1.	0.091	0.085
	2.	0.091	0.083
	3.	0.082	0.077
	4.	0.083	0.081
	5.	0.081	0.081
	6.	0.080	0.079
	7.	0.085	0.079
	8.	0.085	0.074
	9.	0.069	0.080
	10.	0.078	0.077
	11.	0.086	0.083
	12.	0.098	0.083
	13.	0.080	0.087
	14.	0.081	0.073
	15.	0.079	0.077

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.2211

FABRIC 8: 55/45 poly/wool pants

		SIDE1	SIDE2
COMP.	1.	0.177	0.139
	2.	0.175	0.119
	3.	0.167	0.123
	4.	0.213	0.141
	5.	0.193	0.168
	6.	0.203	0.135
	7.	0.195	0.111
	8.	0.178	0.136
	9.	0.193	0.131
	10.	0.181	0.129
	11.	0.169	0.107
	12.	0.161	0.124
	13.	0.179	0.139
	14.	0.173	0.137
	15.	0.188	0.142
NCOMP.	1.	0.097	0.068
	2.	0.083	0.065
	3.	0.087	0.073
	4.	0.087	0.070
	5.	0.081	0.070
	6.	0.077	0.078
	7.	0.087	0.075
	8.	0.081	0.075
	9.	0.077	0.075
	10.	0.079	0.091
	11.	0.087	0.065
	12.	0.075	0.085
	13.	0.096	0.081
	14.	0.081	0.067
	15.	0.098	0.082

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0001

Measured ply-to-ply attraction force (units in pounds).
(continued)

FABRIC 9: 100 nylon fil. lining

		SIDE1	SIDE2
COMP.	1.	0.021	0.017
	2.	0.021	0.017
	3.	0.021	0.015
	4.	0.019	0.018
	5.	0.016	0.015
	6.	0.030	0.014
	7.	0.017	0.013
	8.	0.025	0.015
	9.	0.021	0.015
	10.	0.014	0.022
	11.	0.023	0.015
	12.	0.013	0.012
	13.	0.012	0.014
	14.	0.018	0.014
	15.	0.023	0.015
NCOMP.	1.	0.015	0.014
	2.	0.014	0.013
	3.	0.015	0.013
	4.	0.017	0.014
	5.	0.015	0.015
	6.	0.013	0.012
	7.	0.016	0.013
	8.	0.011	0.011
	9.	0.012	0.012
	10.	0.013	0.015
	11.	0.014	0.013
	12.	0.015	0.013
	13.	0.013	0.014
	14.	0.011	0.012
	15.	0.013	0.014

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0030

FABRIC 10: 100% cot poplin

		SIDE1	SIDE2
COMP.	1.	0.184	0.120
	2.	0.195	0.112
	3.	0.202	0.122
	4.	0.183	0.134
	5.	0.194	0.121
	6.	0.159	0.095
	7.	0.161	0.123
	8.	0.171	0.138
	9.	0.184	0.141
	10.	0.212	0.143
	11.	0.164	0.113
	12.	0.189	0.125
	13.	0.189	0.123
	14.	0.179	0.124
	15.	0.181	0.113
NCOMP.	1.	0.104	0.098
	2.	0.092	0.093
	3.	0.101	0.087
	4.	0.083	0.085
	5.	0.069	0.073
	6.	0.124	0.123
	7.	0.102	0.104
	8.	0.093	0.075
	9.	0.093	0.095
	10.	0.091	0.080
	11.	0.088	0.088
	12.	0.097	0.084
	13.	0.093	0.081
	14.	0.095	0.085
	15.	0.095	0.087

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0001

Measured ply-to-ply attraction force (units in pounds).
(continued)

FABRIC 11: 55/45 poly/wool pants

		SIDE1	SIDE2
COMP.	1.	0.142	0.075
	2.	0.122	0.010
	3.	0.121	0.125
	4.	0.187	0.125
	5.	0.184	0.130
	6.	0.127	0.094
	7.	0.164	0.111
	8.	0.182	0.118
	9.	0.176	0.131
	10.	0.201	0.145
	11.	0.152	0.104
	12.	0.190	0.113
	13.	0.166	0.123
	14.	0.192	0.131
	15.	0.173	0.109
NCOMP.	1.	0.077	0.073
	2.	0.089	0.093
	3.	0.079	0.071
	4.	0.085	0.078
	5.	0.083	0.063
	6.	0.077	0.072
	7.	0.103	0.087
	8.	0.082	0.067
	9.	0.066	0.085
	10.	0.064	0.063
	11.	0.065	0.069
	12.	0.080	0.069
	13.	0.079	0.065
	14.	0.079	0.077
	15.	0.024	0.077

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0001

FABRIC 12: 50/50 poly/cot pants

		SIDE1	SIDE2
COMP.	1.	0.124	0.088
	2.	0.139	0.099
	3.	0.145	0.106
	4.	0.157	0.135
	5.	0.153	0.109
	6.	0.111	0.085
	7.	0.127	0.098
	8.	0.125	0.102
	9.	0.153	0.121
	10.	0.133	0.125
	11.	0.112	0.095
	12.	0.141	0.118
	13.	0.163	0.135
	14.	0.162	0.136
	15.	0.151	0.123
NCOMP.	1.	0.063	0.063
	2.	0.071	0.070
	3.	0.074	0.070
	4.	0.078	0.065
	5.	0.085	0.066
	6.	0.075	0.067
	7.	0.085	0.068
	8.	0.091	0.069
	9.	0.112	0.096
	10.	0.120	0.091
	11.	0.074	0.084
	12.	0.073	0.069
	13.	0.079	0.071
	14.	0.067	0.061
	15.	0.075	0.080

EFFECT	PROB. > F-VALUE
COMPRESSION	0.0001
SIDE	0.0001

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

AIR FLOTATION TABLES

(PAPER NOT AVAILABLE)

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

ROBOT ASSISTED SHIRT COLLAR ASSEMBLY

ROBOT ASSISTED MATERIAL HANDLING FOR SHIRT COLLAR MANUFACTURING - TURNING AND PRESSING

A Research Program

through

Clemson Apparel Research
Advanced Apparel Manufacturing Technology
Demonstration Center

by

Center for Advanced Manufacturing
Mechanical Engineering Department
Clemson University
Clemson, SC 29634-0921

Presented at
The Advanced Apparel Manufacturing Technology Conference

February 14-16, 1990
Philadelphia College of Textiles and Science
Philadelphia, PA 19144

by

Frank W. Paul, Principal Investigator
McQueen Quattlebaum Professor of Mechanical Engineering
Director, Center for Advanced Manufacturing

SUMMARY

This project addresses the development of a robot assisted apparel workstation for the turning and pressing of shirt collars. The project considers the modification and improvement of the single point collar turning and pressing process by studying and developing an automated double point pressing and turning workstation. This workstation will be design in such a way that the resulting technology will also be useful for the design of double point turning and pressing machines which do not require robot assisted fabric handling.

The current research on this project is addressing the following tasks.

1. Design, development and evaluation of a double point collar turning device.
2. Design, development and evaluation of a double point pressing device.
3. Design, development and evaluation of a robot end-effector which can manipulate collars in conjunction with the collar turning and pressing devices.
4. Development, evaluation and integration of vision based information for collar point and seam alignment.
5. Development, evaluation and integration of an "intelligent" strategy for workstation planning, control and system operation.

The project is under the guidance of a Technical Advisory Board composed of representatives from the apparel manufacturing, machine manufacturing and apparel research areas. The goal of this project is to demonstrate an integrated proof-of-concept apparel workstation for double point turning and pressing of shirt collars using robot assisted material handling.

The following figures were used for a presentation at the AAMTD Conference. The figures provide an overview of the project at this time. Detail device design information is not included because of patent considerations. General information is provided concerning the computer controller software scheme, workstation configuration, operation sequence and project status.

ROBOT ASSISTED COLLAR TURNING AND PRESSING

PROGRAM OVERVIEW

- PROGRAM MANAGEMENT
- PROGRAM DEVELOPMENT
- TECHNOLOGY REVIEW

SPECIFIC TECHNOLOGY

- SYSTEMS CONCEPTS
- TURNING TECHNOLOGY
- ROBOT ASSISTED COLLAR HANDLING
- PRESSING TECHNOLOGY
- ROBOT SELECTION AND VISION SENSING

RESEARCH TEAM

Frank W. Paul, PI

Staff

S. Avigdor, Visiting Scholar
- Collar Turning Mechanism

A. Aspland, Engr Assoc, CAR
- Systems and Component Design

Graduate Students

E. Torgerson, PhD Student
- Systems Integration/Robotics

D. Cultice, MS Student
- Vision/Robotics

A. Gopalswamy, MS Student
- Robot End-Effector

K. Subba-Rao, MS Student
- Collar Pressing Mechanism

Undergraduate Students

Elizabeth Anton

Russell Roman

TECHNICAL ADVISORY BOARD
DLA/CAR/CAM Research Project

Mr. Harry Berzack
President, The Fox Company

Mr. William Epstein
President, Iva Manufacturing

Mr. Charles Gilbert
President, Gilbert Associates

Mr. Edward Hill
Site Director, Clemson Apparel Research

Mr. William Mitchell
Director, R&D, Oxford Industries

Mr. Ernst Schramayr
President, Jet-Sew, Cluett Peabody

Dr. Paul Taylor
Professor, University of Hull, UK

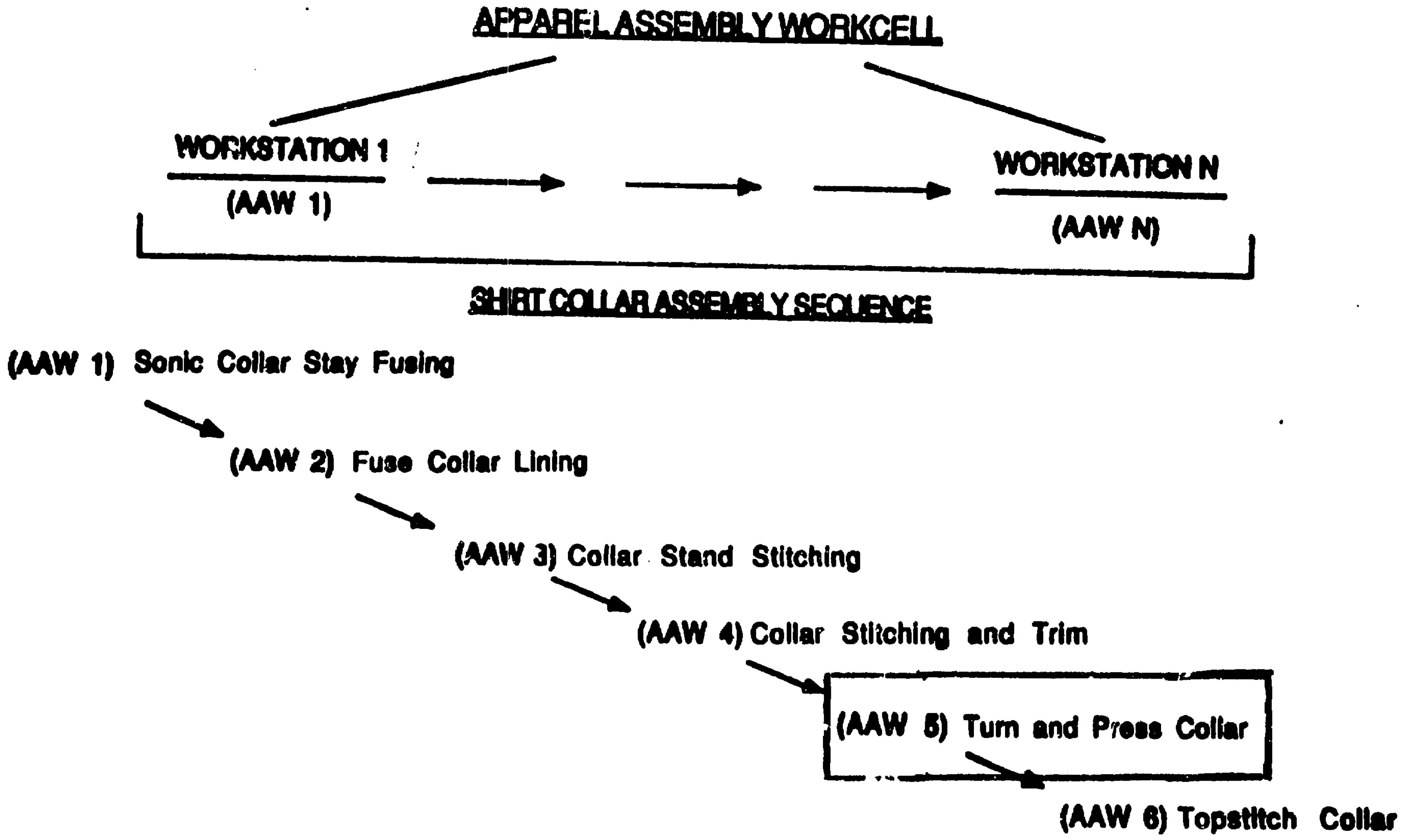
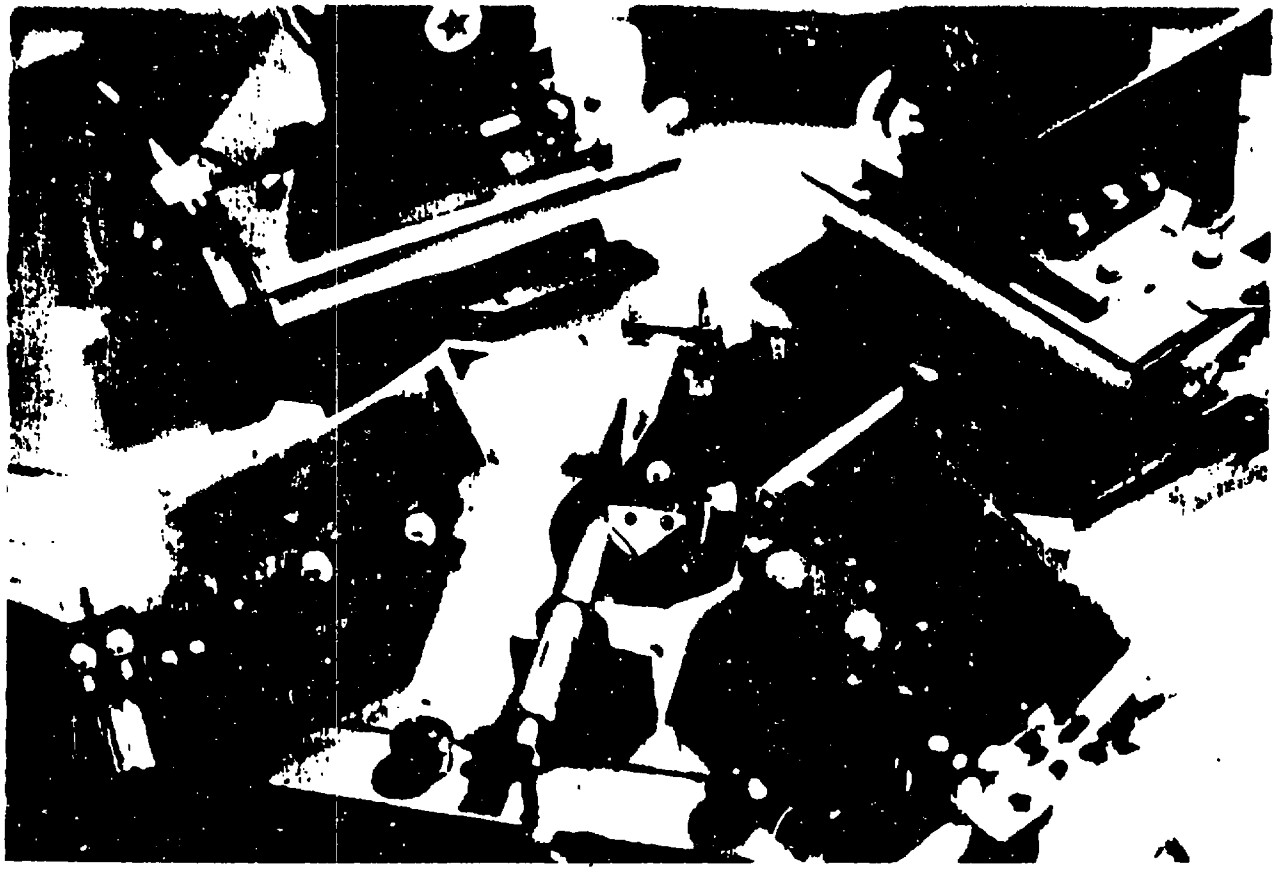


FIGURE 1 APPAREL ASSEMBLY WORKCELL
FOR SHIRT COLLAR TASKS

A... ..89 Rev



MACHINE PRESS COLLAR TURNER AND PRESSER

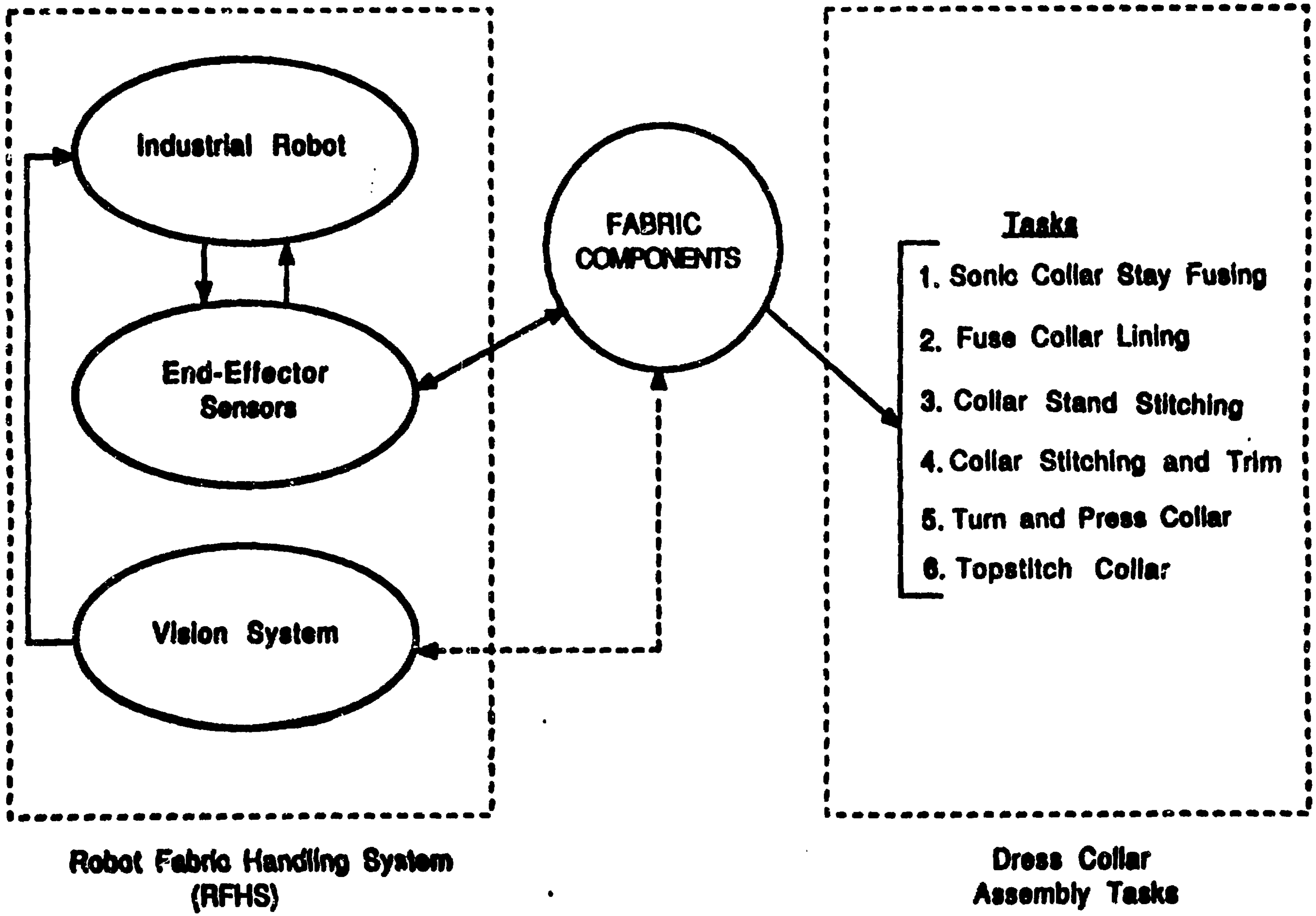


FIGURE 2 Apparel Assembly Workstation (AAW)

April 1989 Rev

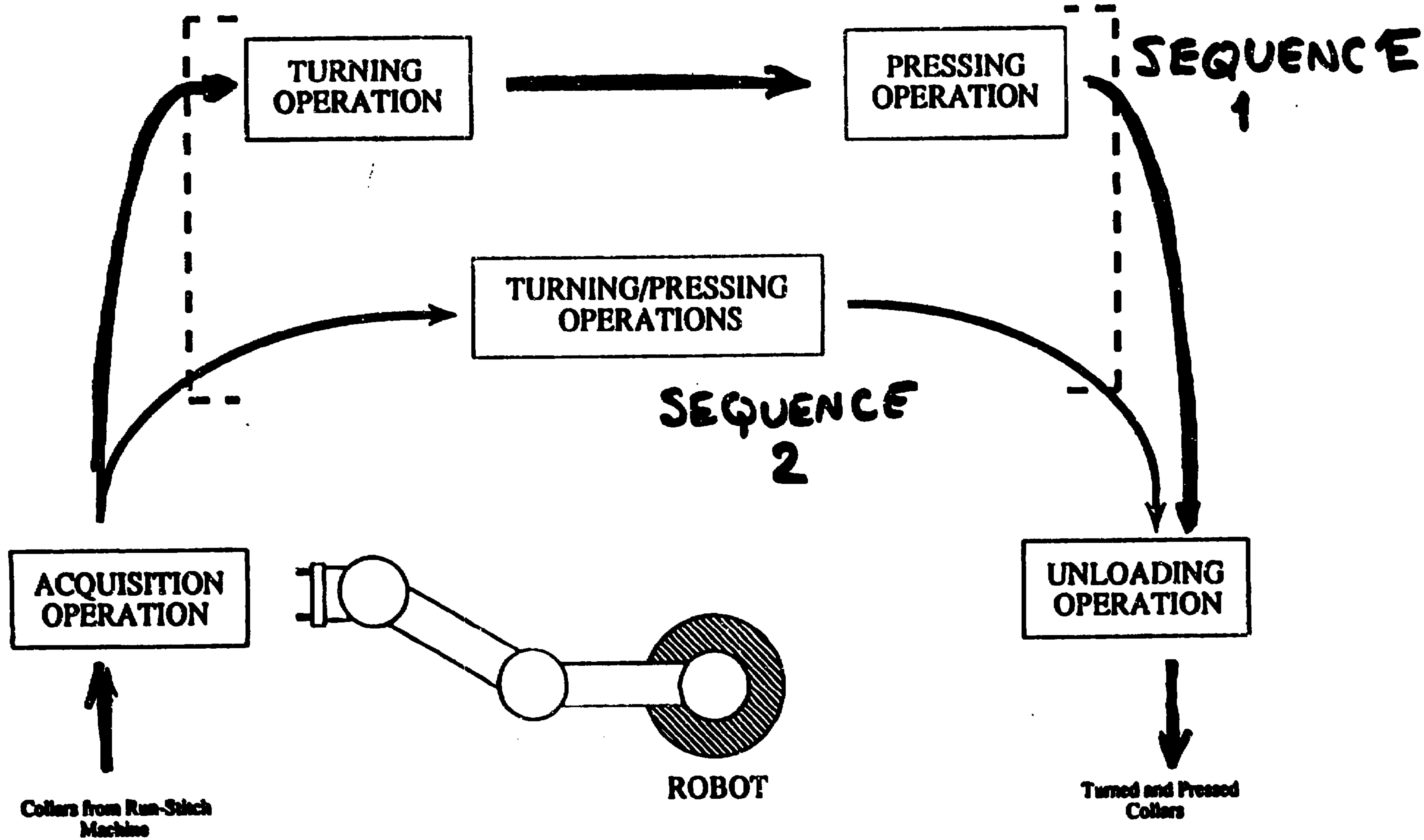
TECHNOLOGY REVIEW

- Research Site Visits
  - Jet Sew
  - Cluett Peabody Research
  - Draper Labs/(TC)2
  - North Carolina State Textiles
  - (TC)2
- Future Site Visits
  - Hull University (Nov 89)
  - Durham University (Nov 89)
  - Philadelphia School of Textiles (Feb 90)
  - JIAM, Tokyo (May 90)

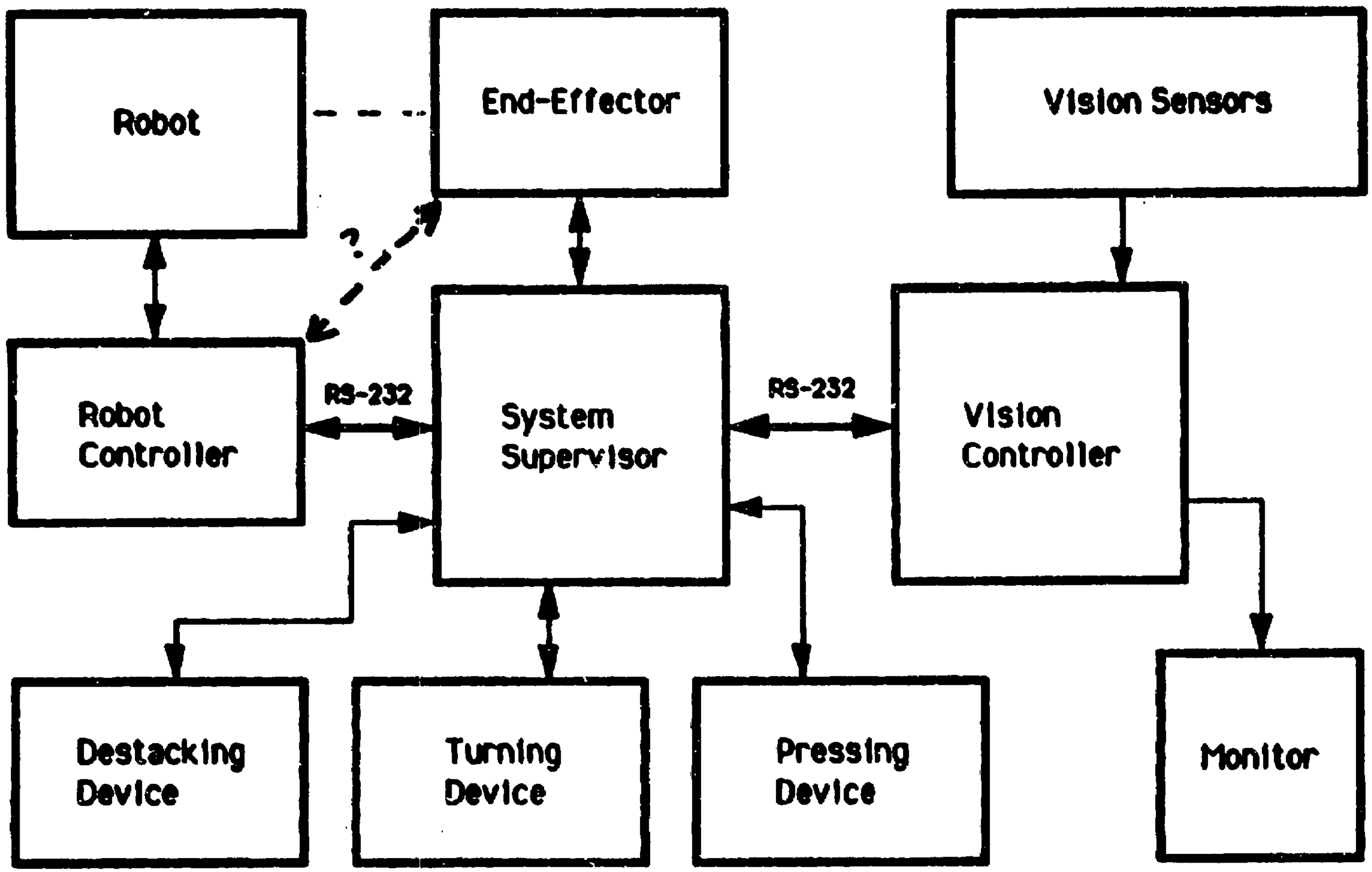
DESIGN PHILOSOPHY

- CREATE OPERATION MACHINE DESIGNS WHICH CAN BE EVALUATED USING EITHER ROBOT ASSISTANCE OR HUMAN INTERACTION
- ADDRESS DOUBLE POINT TURNING AND PRESSING

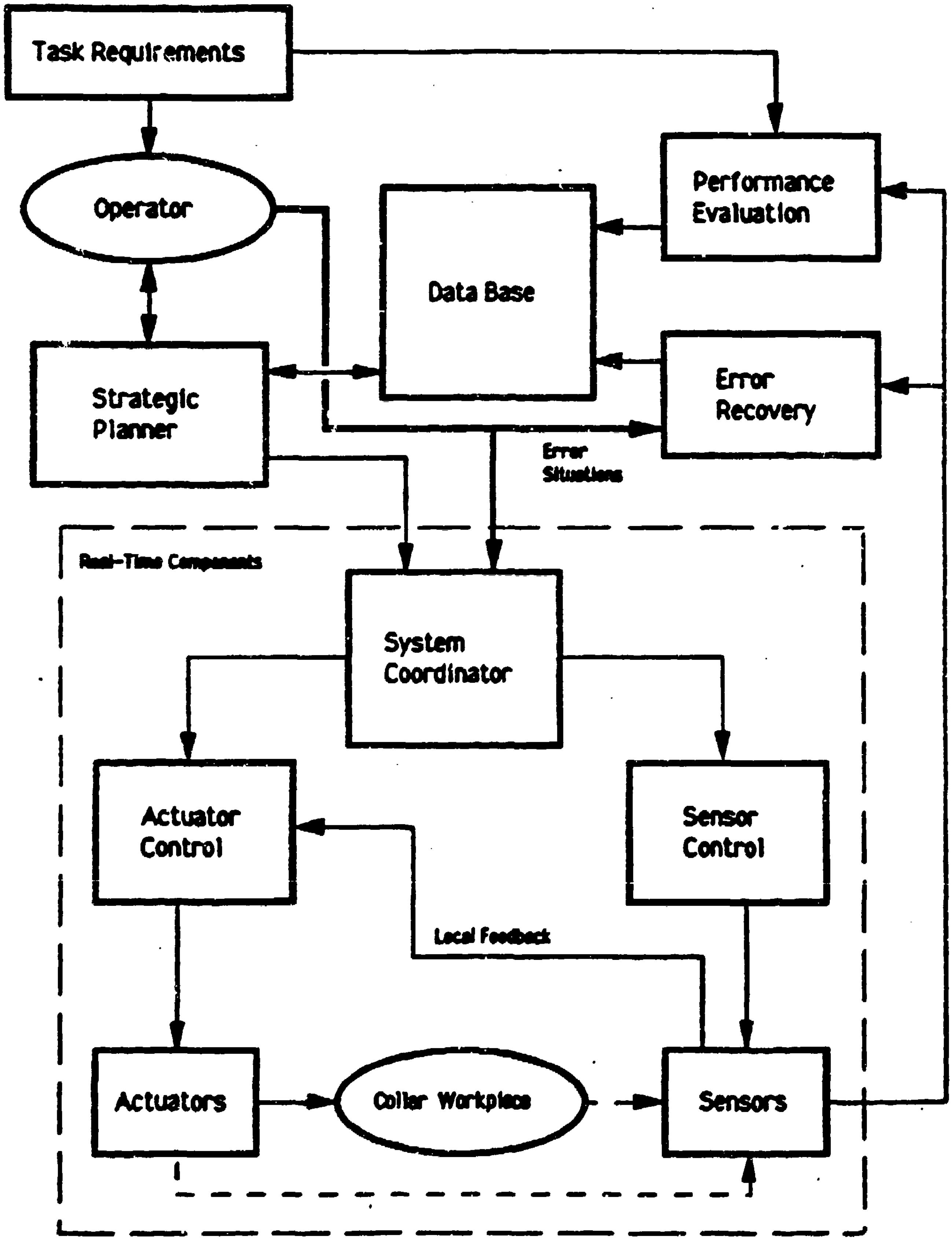
PROCESS SEQUENCE



PROGRAM DESIGN PLANNING



AAW System Configuration



ODCAP Layout

OPERATOR DRIVEN CONTROLLER AND PLANNER

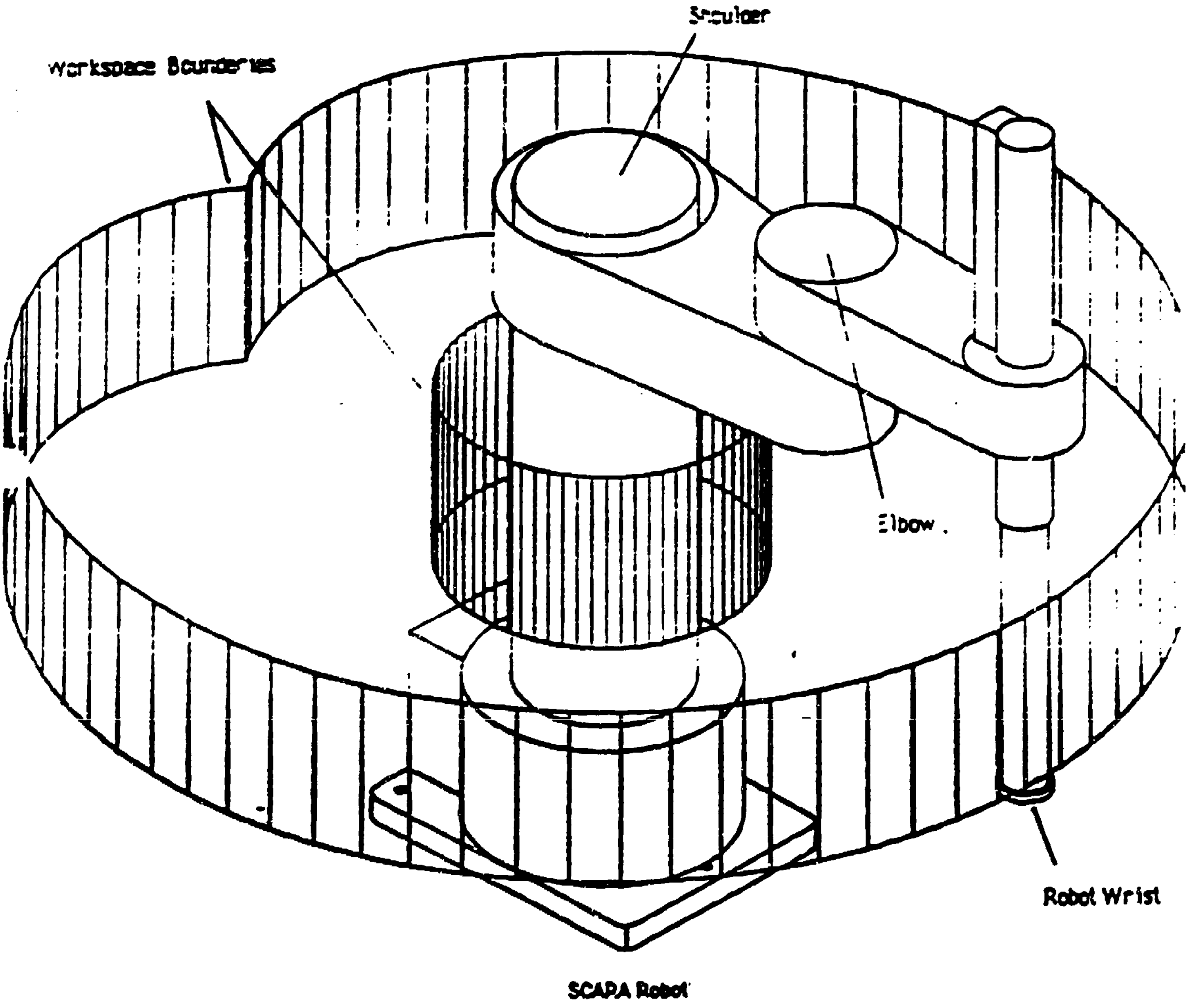
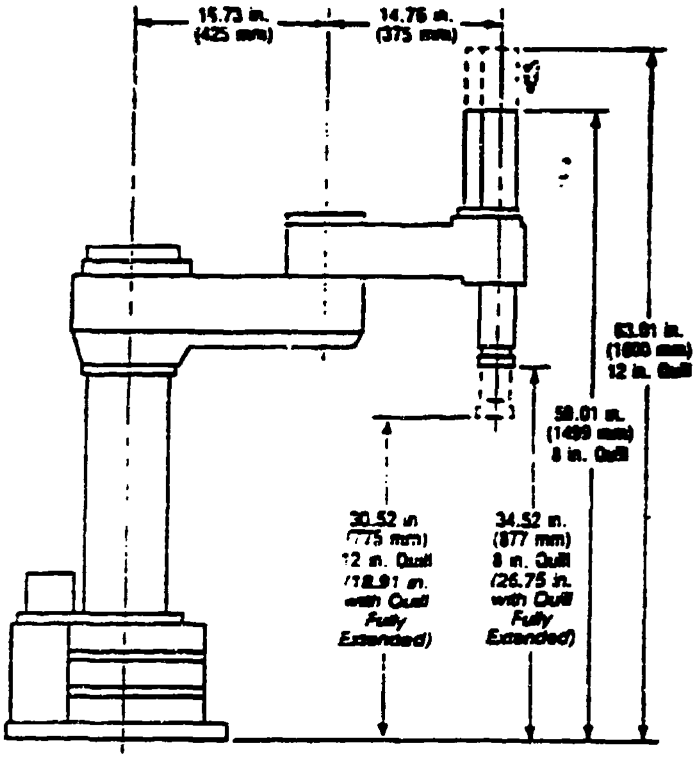


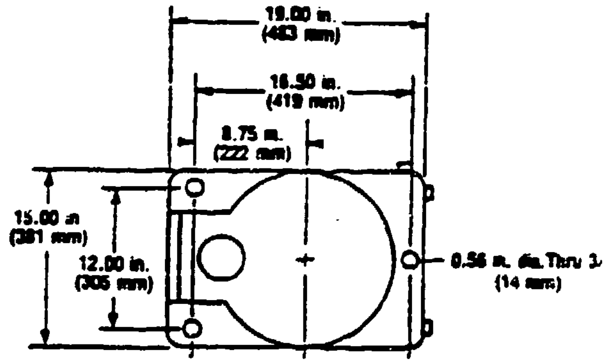
Figure 1. The SCARA Robot and its Workspace

ADEPT ($50,000) /U.S.

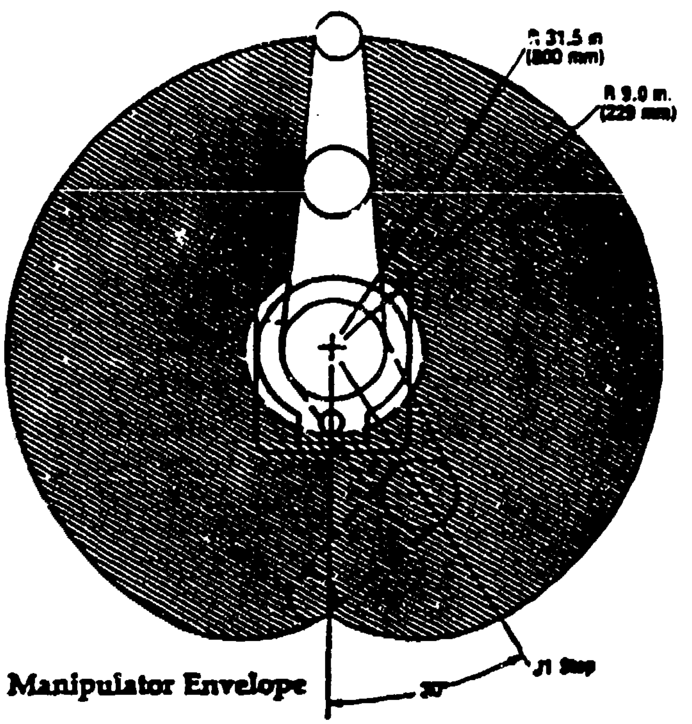
AdeptOne Manipulator Dimensions



Manipulator (side view)



Manipulator Base (plan view)



Manipulator Envelope

Figure 1. The AdeptOne Manipulator: dimensions and workspace.

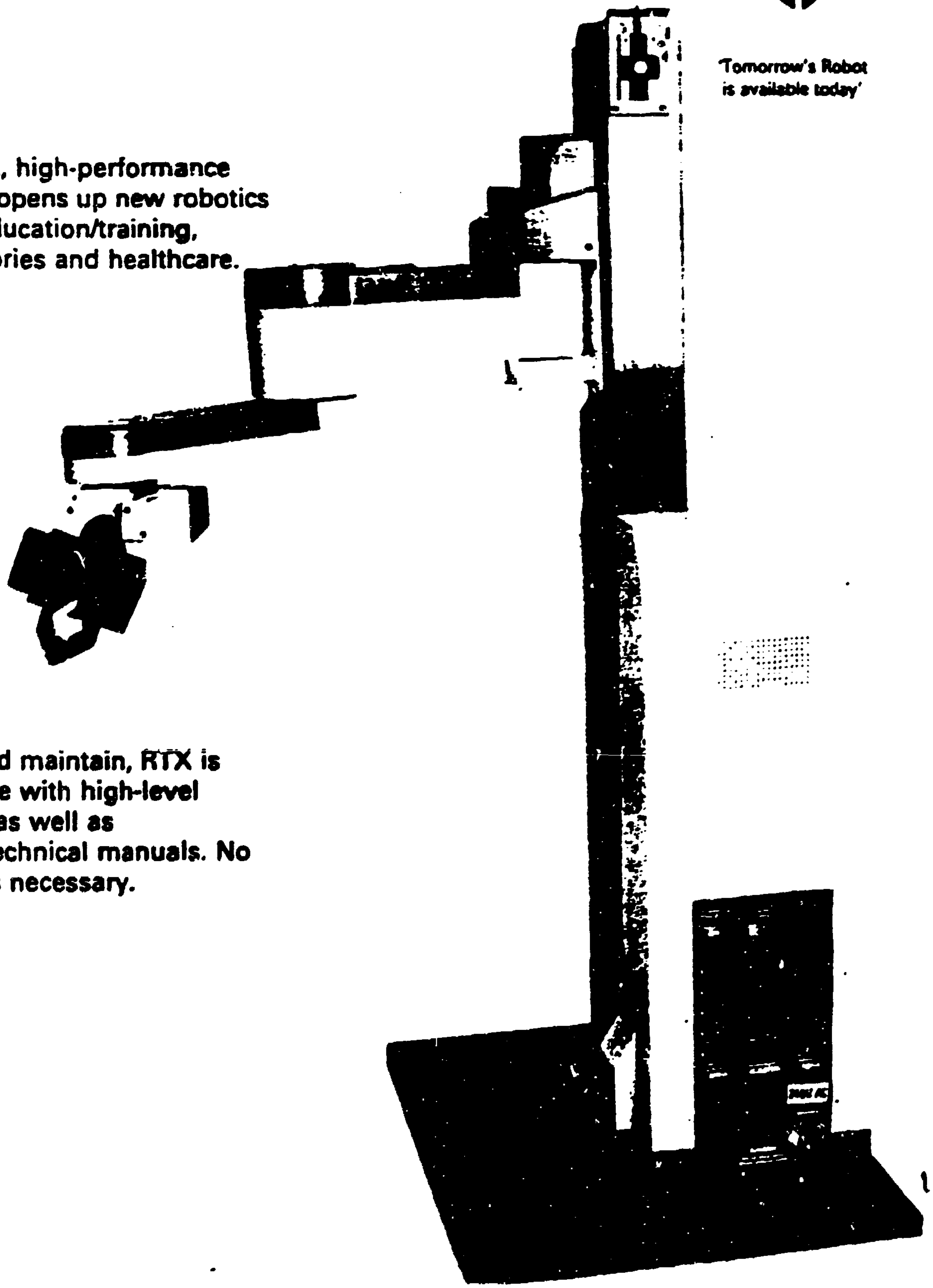
UMI

($10,000) /U.K.

'Tomorrow's Robot is available today'

RTX

RTX is a low-cost, high-performance robot arm which opens up new robotics applications in education/training, industry, laboratories and healthcare.



Easy to install and maintain, RTX is supplied complete with high-level control software as well as comprehensive technical manuals. No special training is necessary.

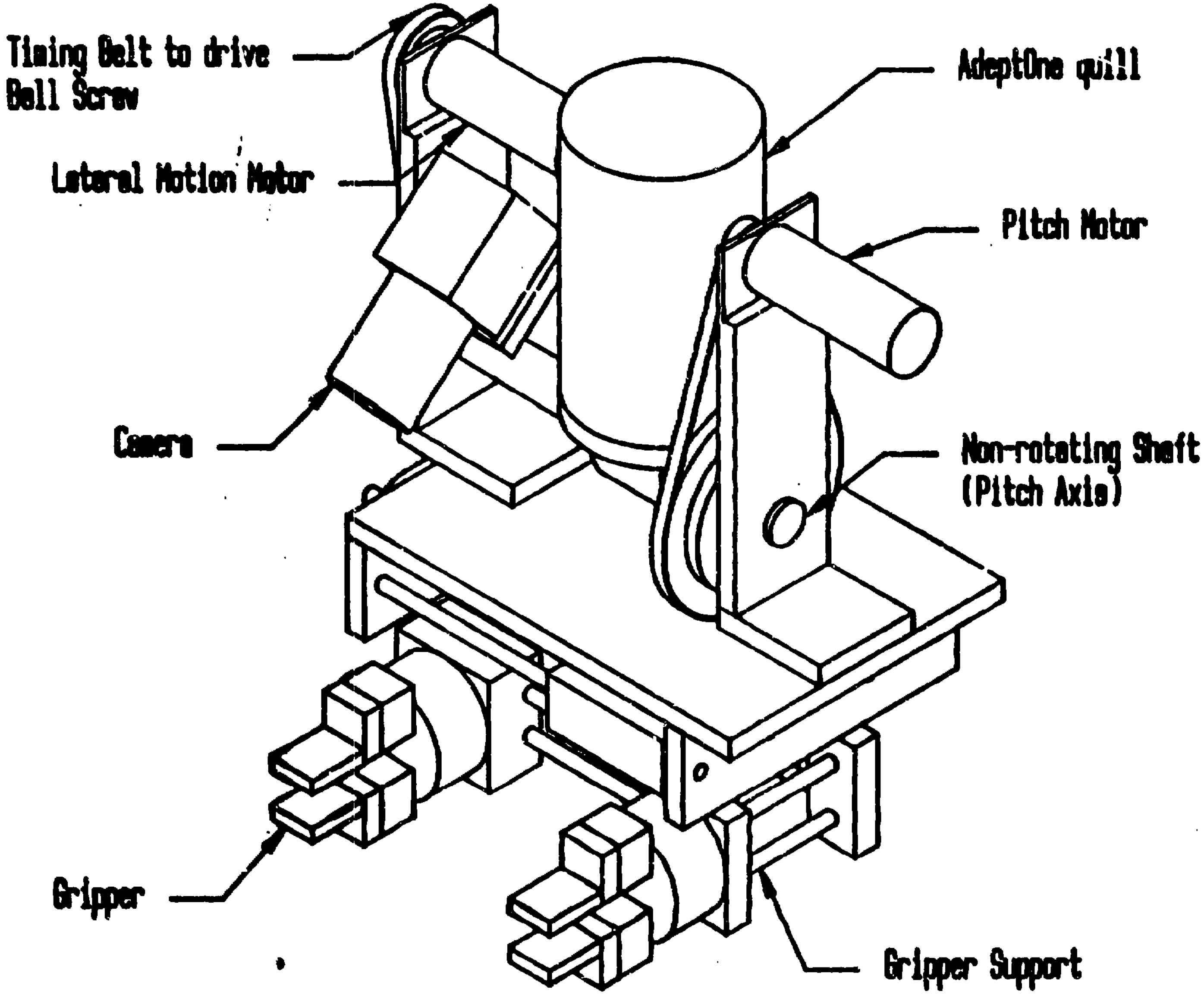


Figure 2. End-Effector Design

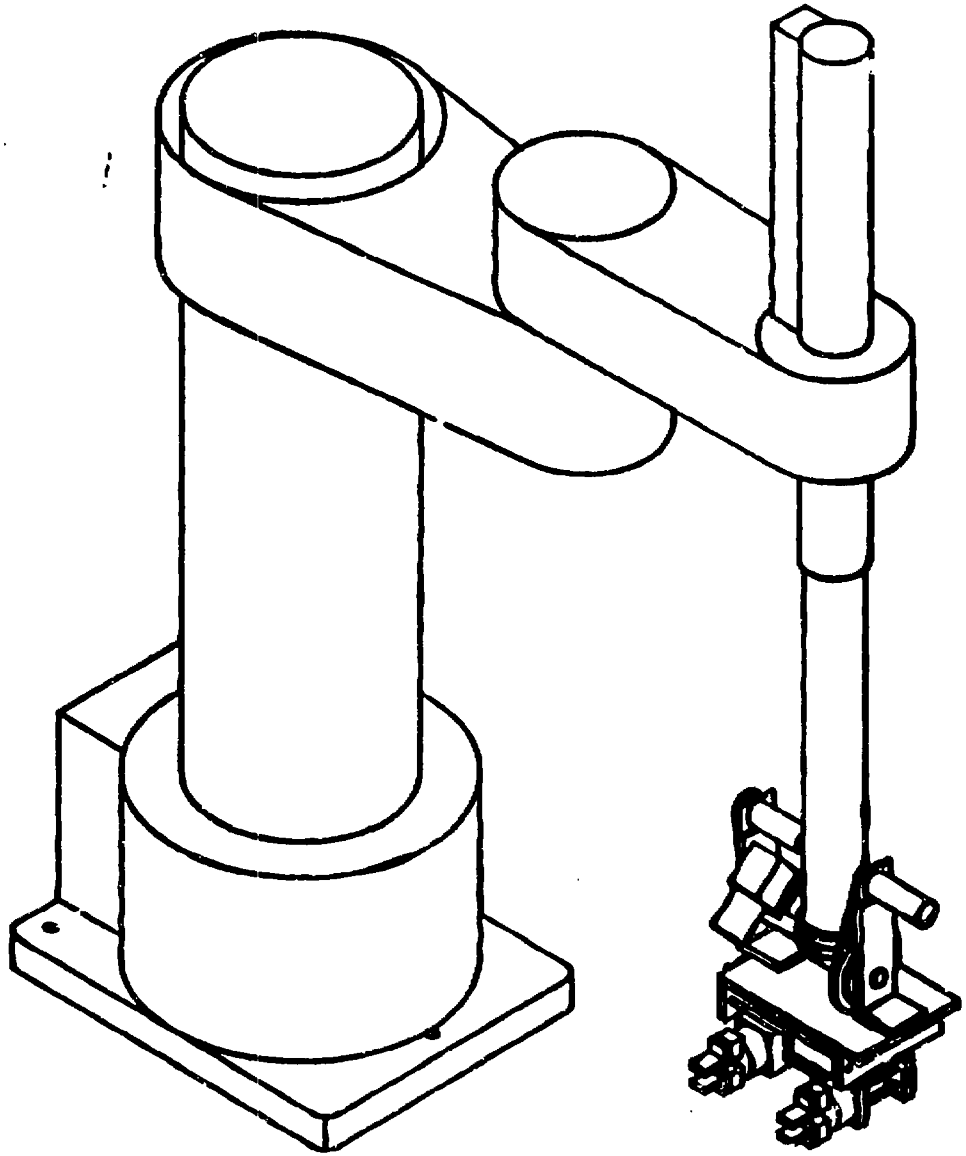
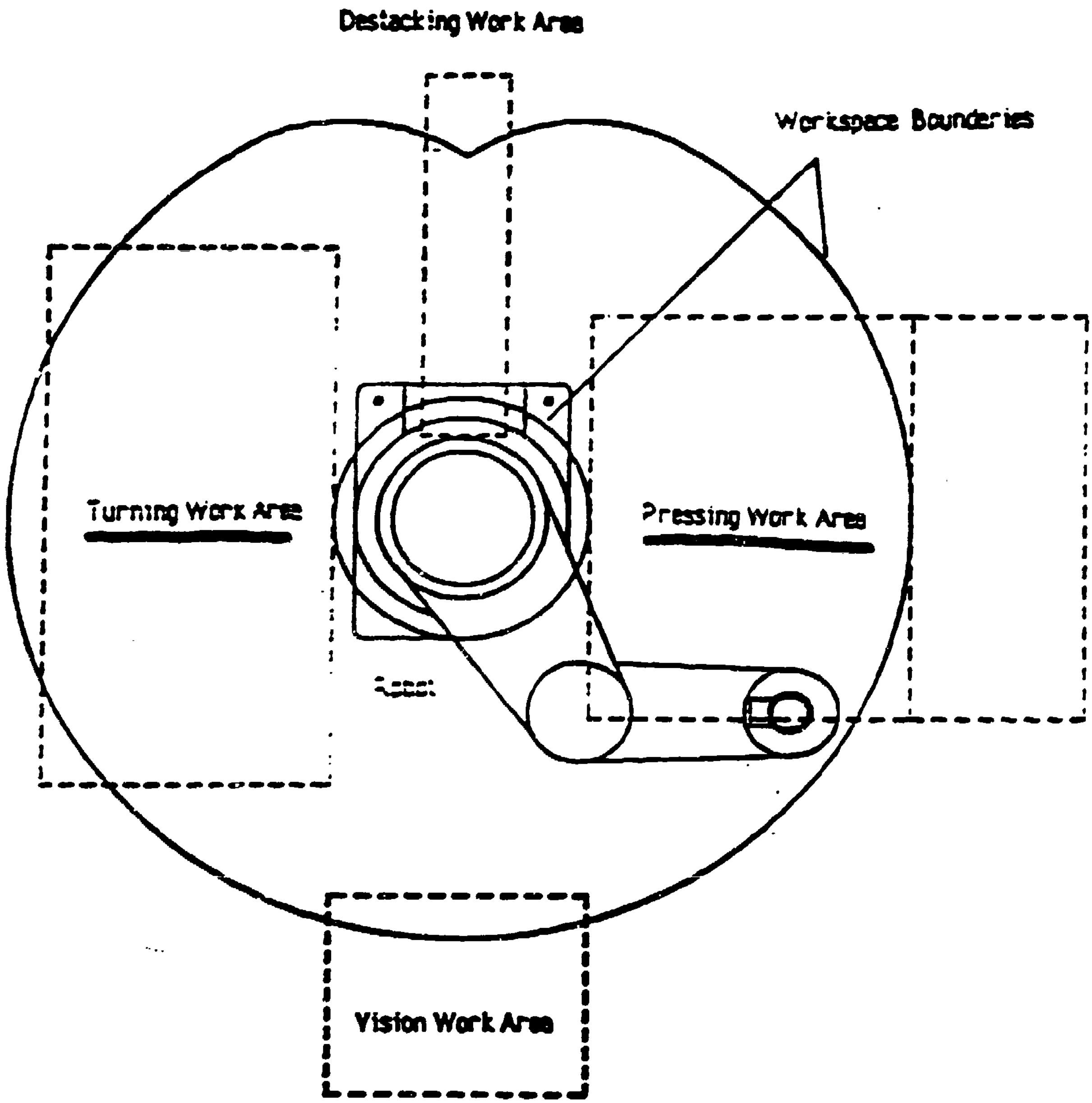


Figure 1. End-Effector Mounted on AdeptOne Robot



ONE CONCEPT LAYOUT
OF AAW

Figure 2. Top View of SCARA Robot and AAW Work Areas

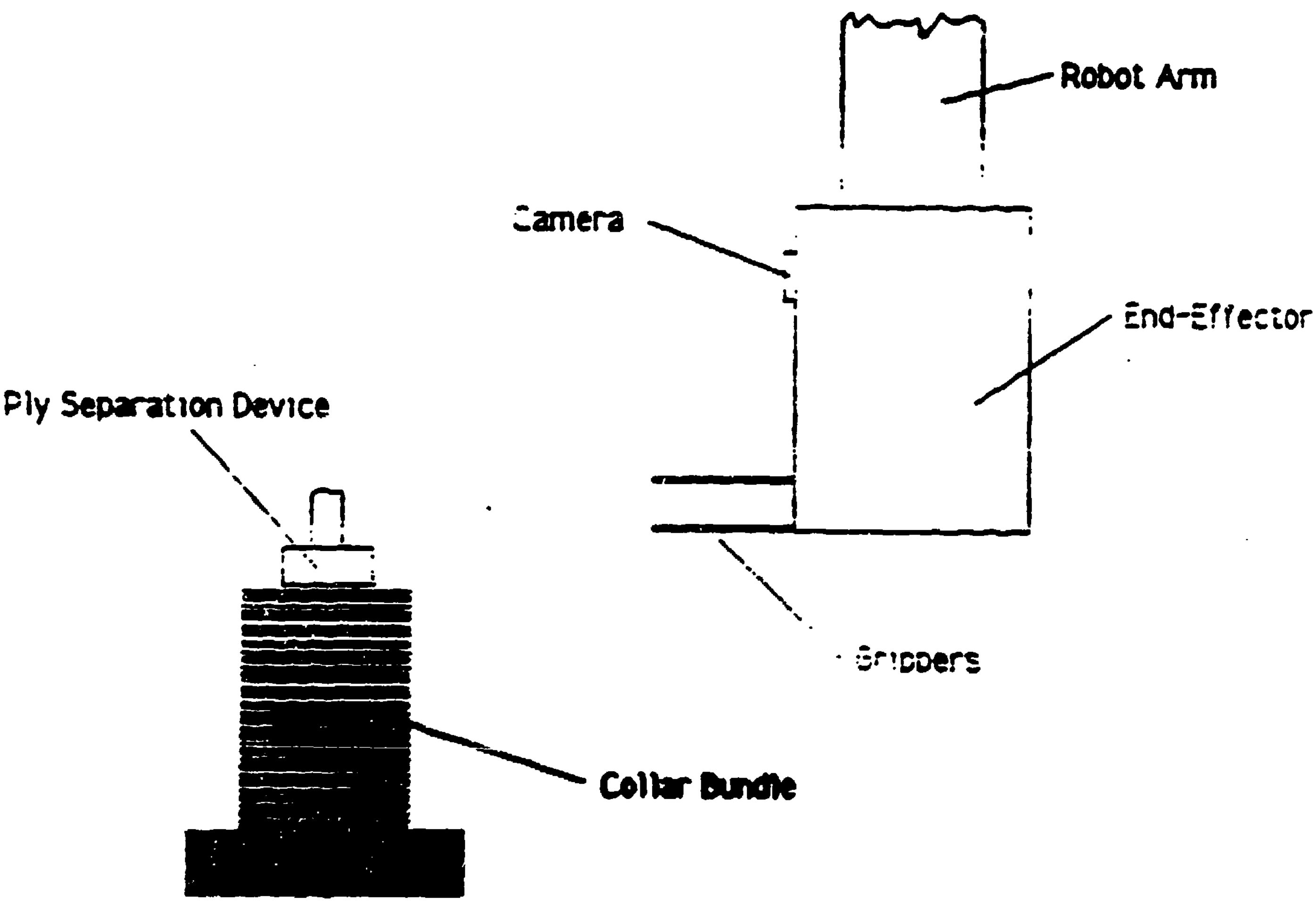


Figure 5. Side View of End-Effector Approaching Destacker

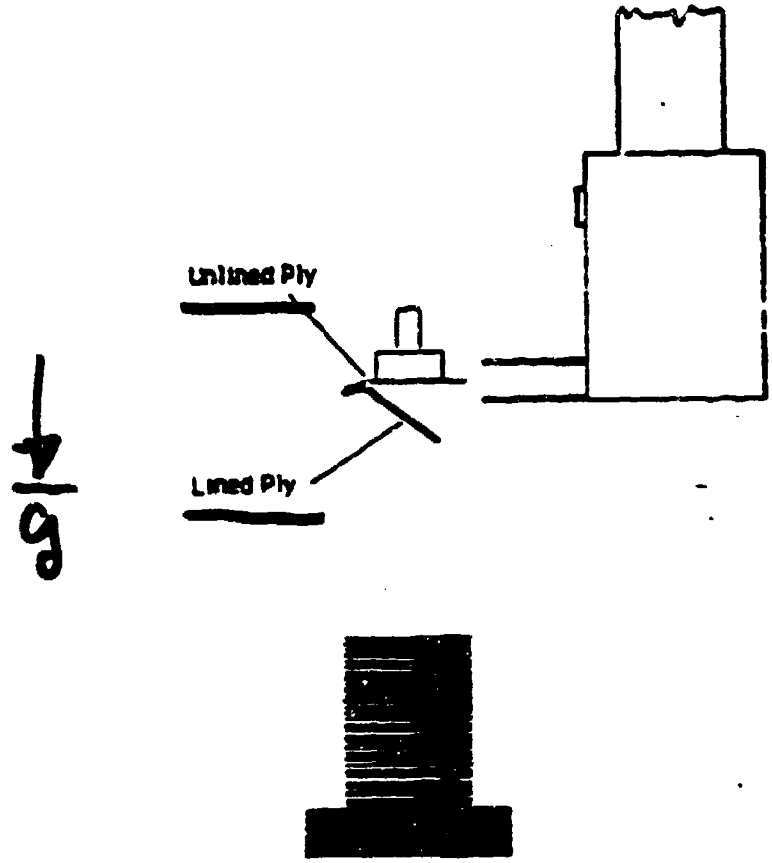


Figure 6. Side View of End-Effector Acquiring Workpiece

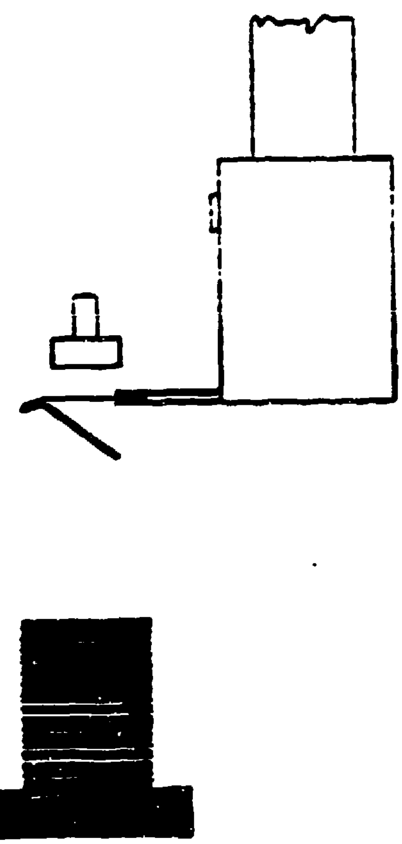


Figure 7. Side View of End-Effector after Workpiece Acquisition

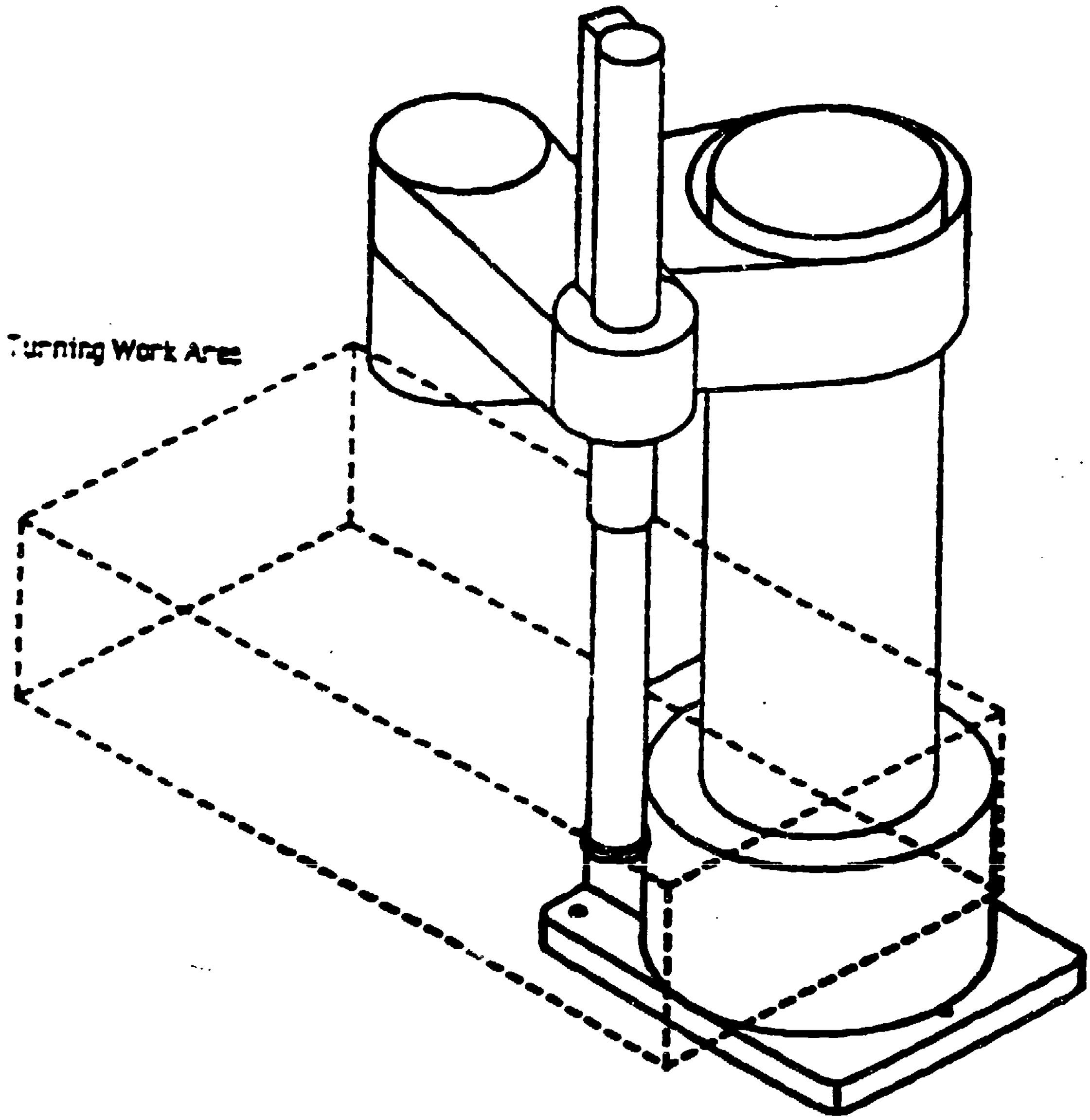


Figure 12. The SCARA Robot in the Turning Work Area

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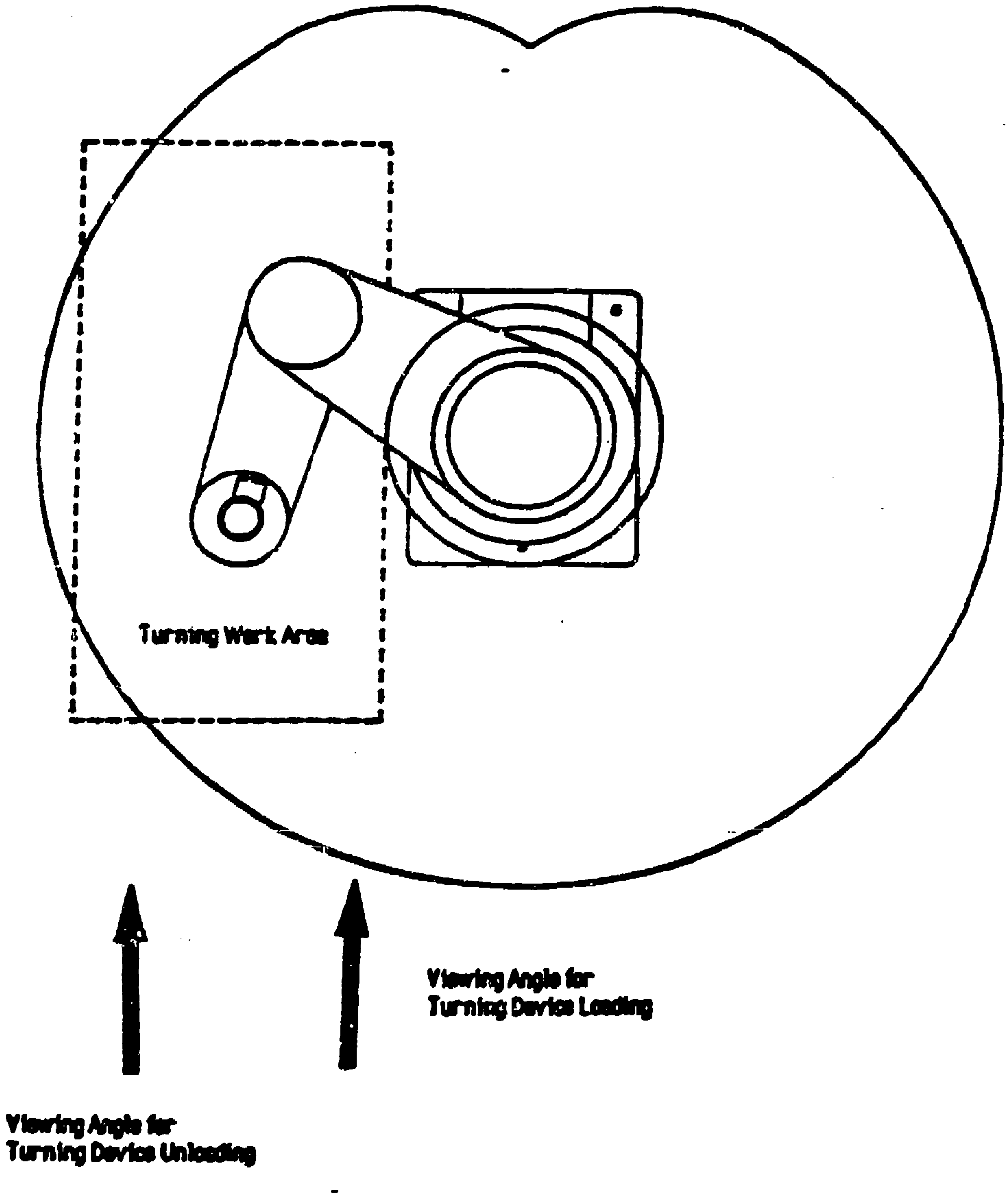

Figure 13. Top View of SCARA Robot in Turning Work Area

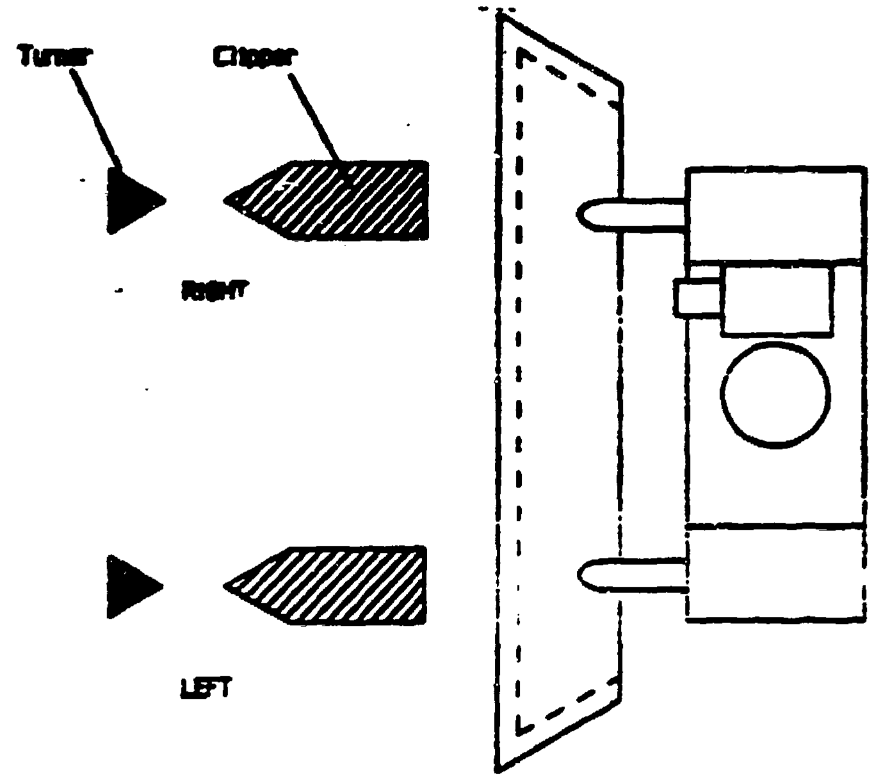

Figure 14. Top View of End-Effector Approaching Turning Device

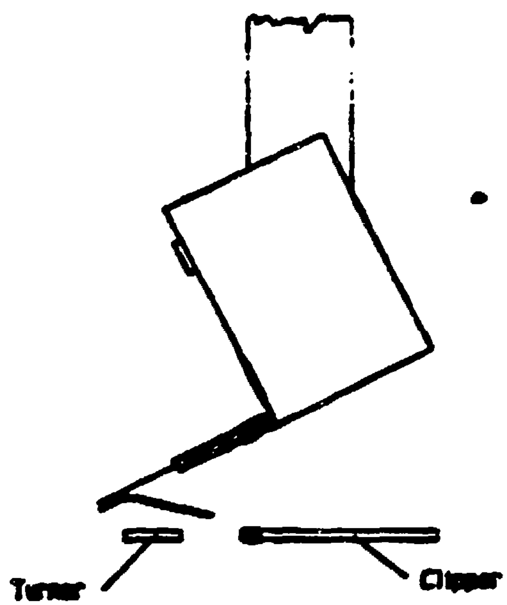

Figure 15. Side View of End-Effector Positioning Lined Ply

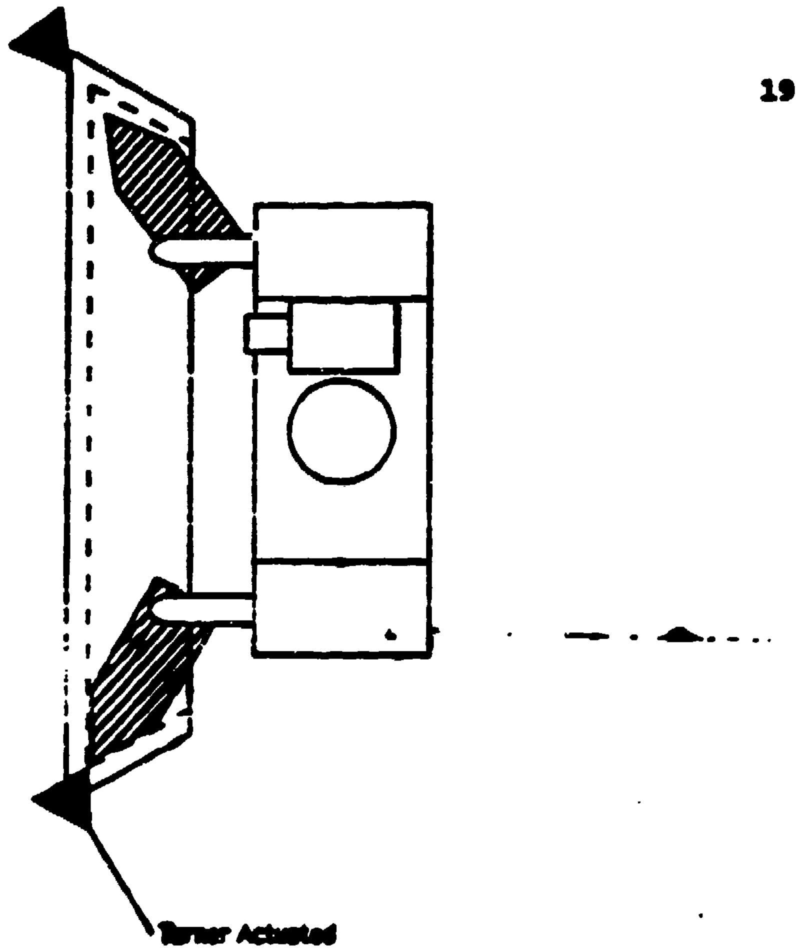

Figure 16. Top View after Placement of Left Collar Point

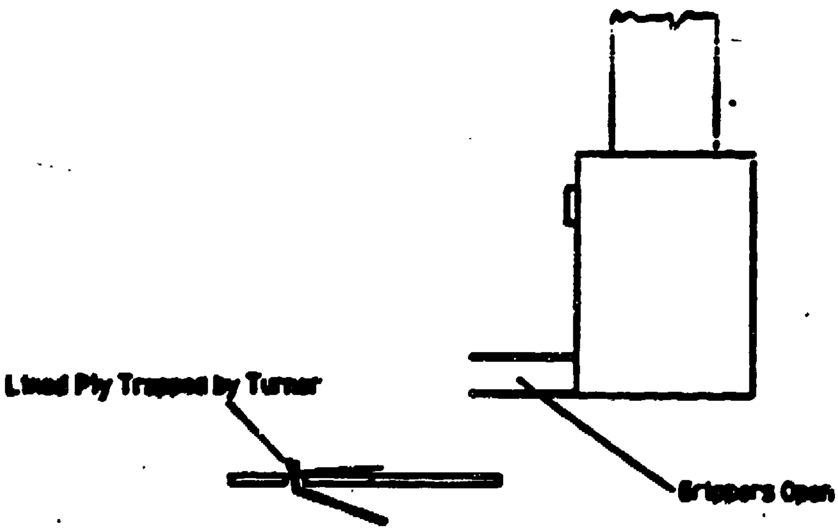

Figure 17. Side View of Workpiece Loaded in Turning Device

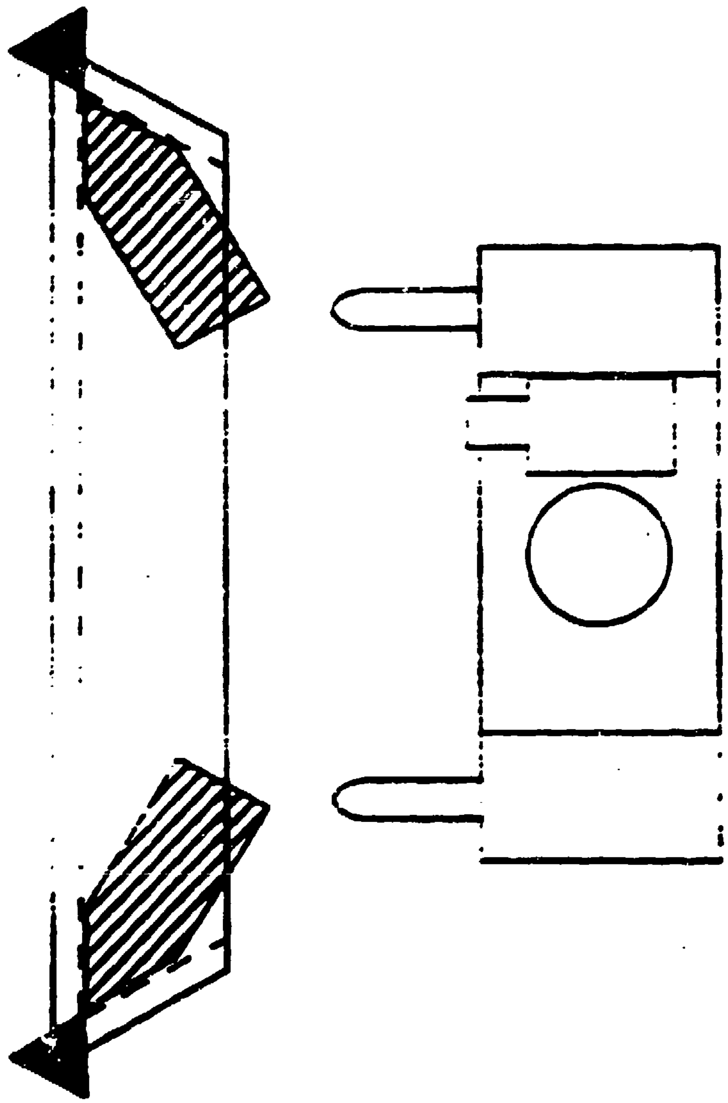

Figure 18. Top View of Workpiece Loaded in Turning Device

25

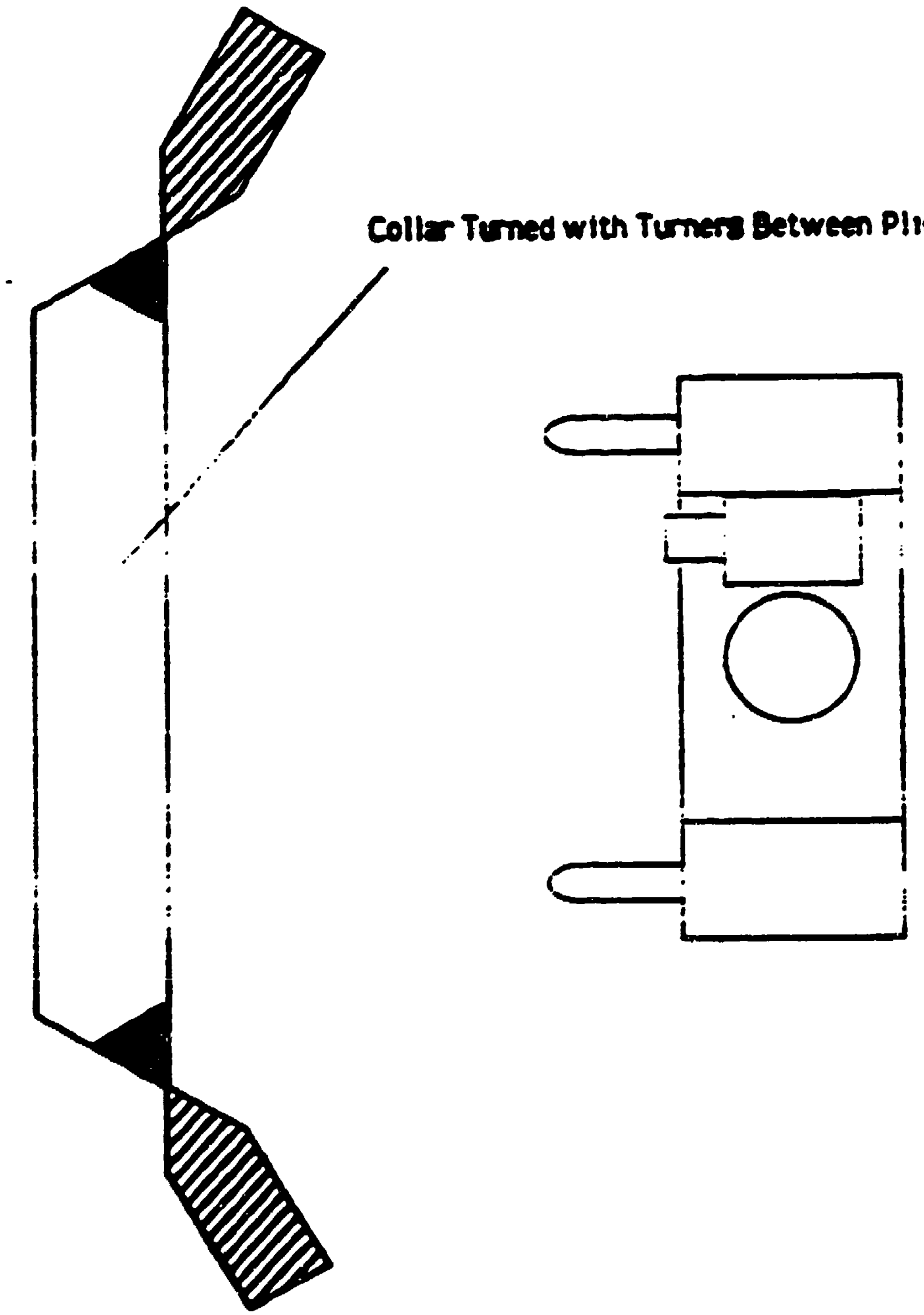

Figure 19. Top View of Workpiece after Undergoing Turning

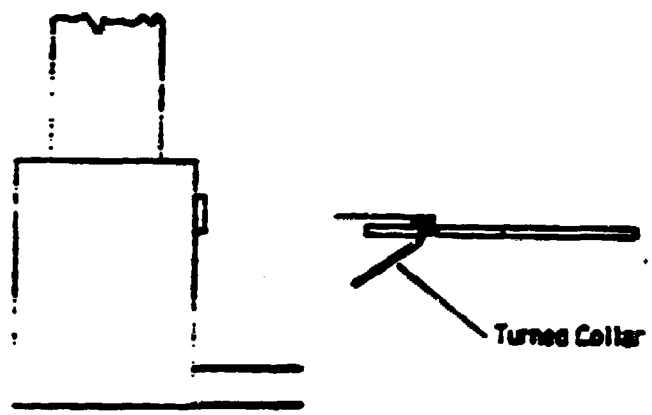

Figure 20. Side View of End-Effector Preparing for Unloading

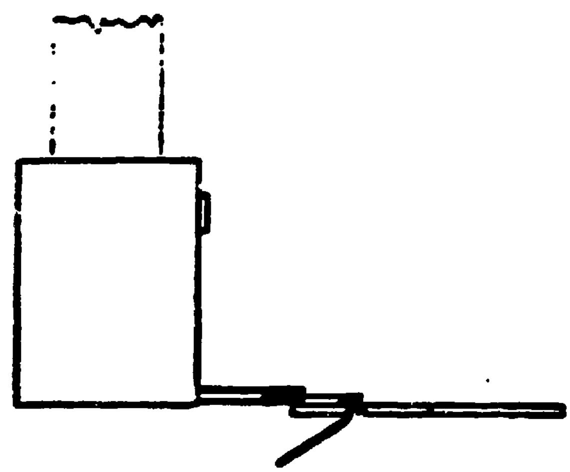

Figure 21. Side View of End-Effector Acquiring Turned Collar

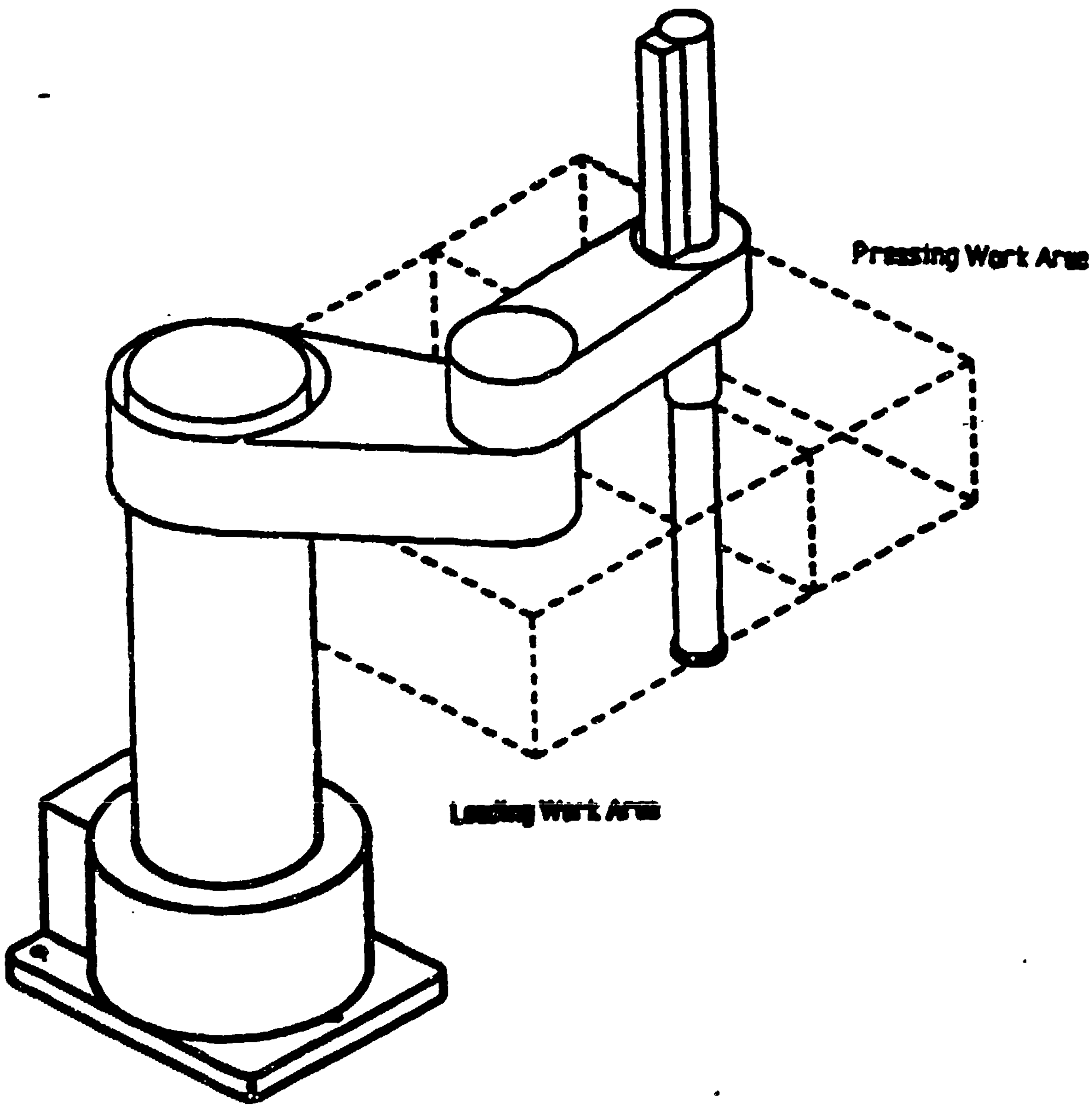

Figure 23. The SCARA Robot in the Pressing Work Area

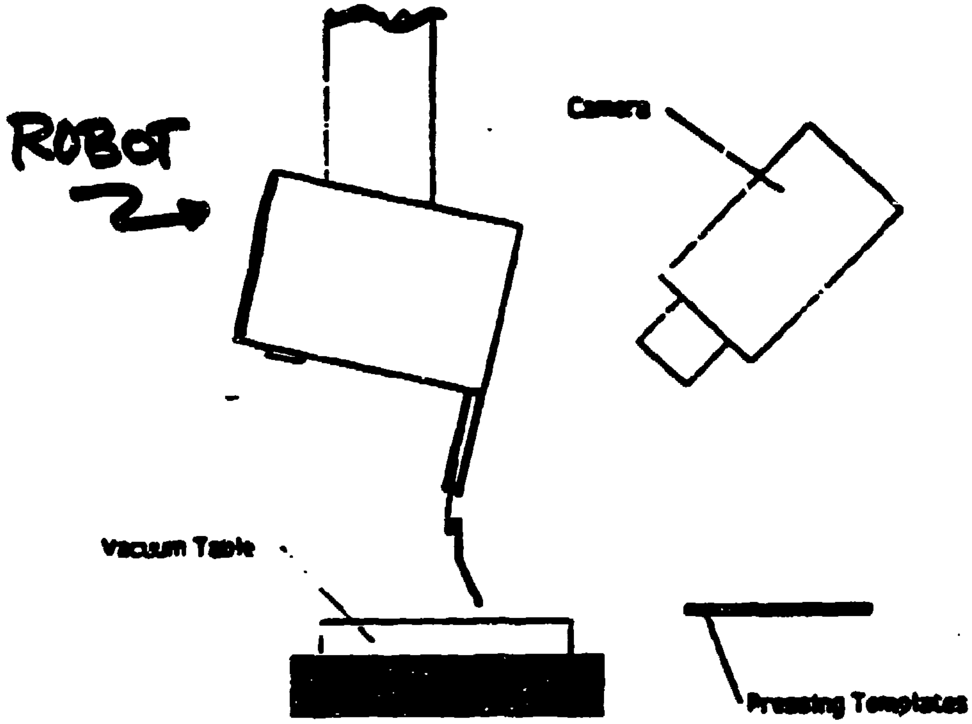

Figure 25. Side View of End-Effector Approaching Pressing Device

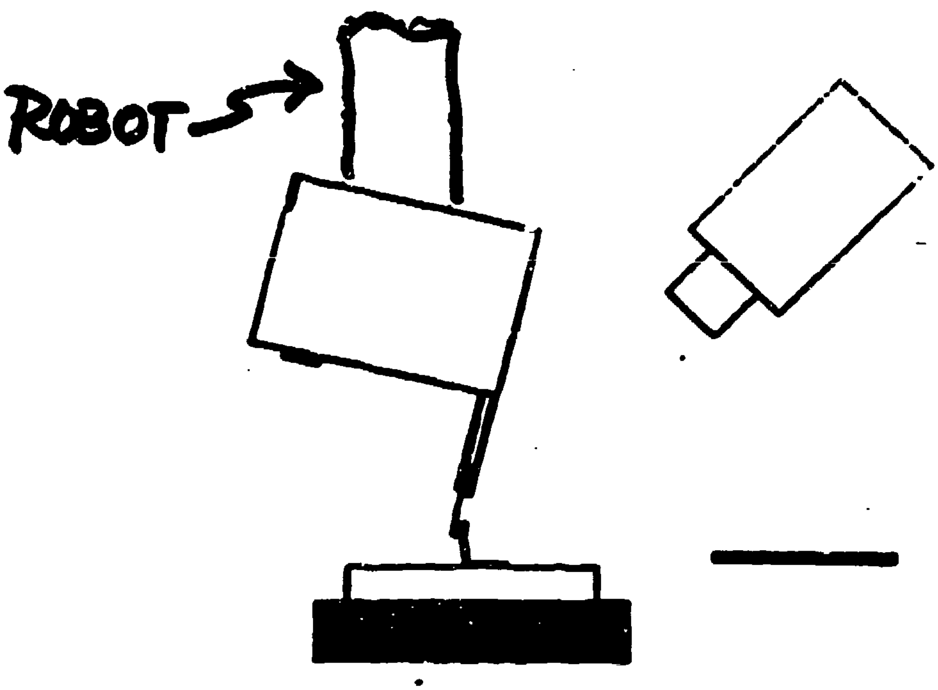

Figure 26. Side View of Workpiece Placement on Vacuum Table

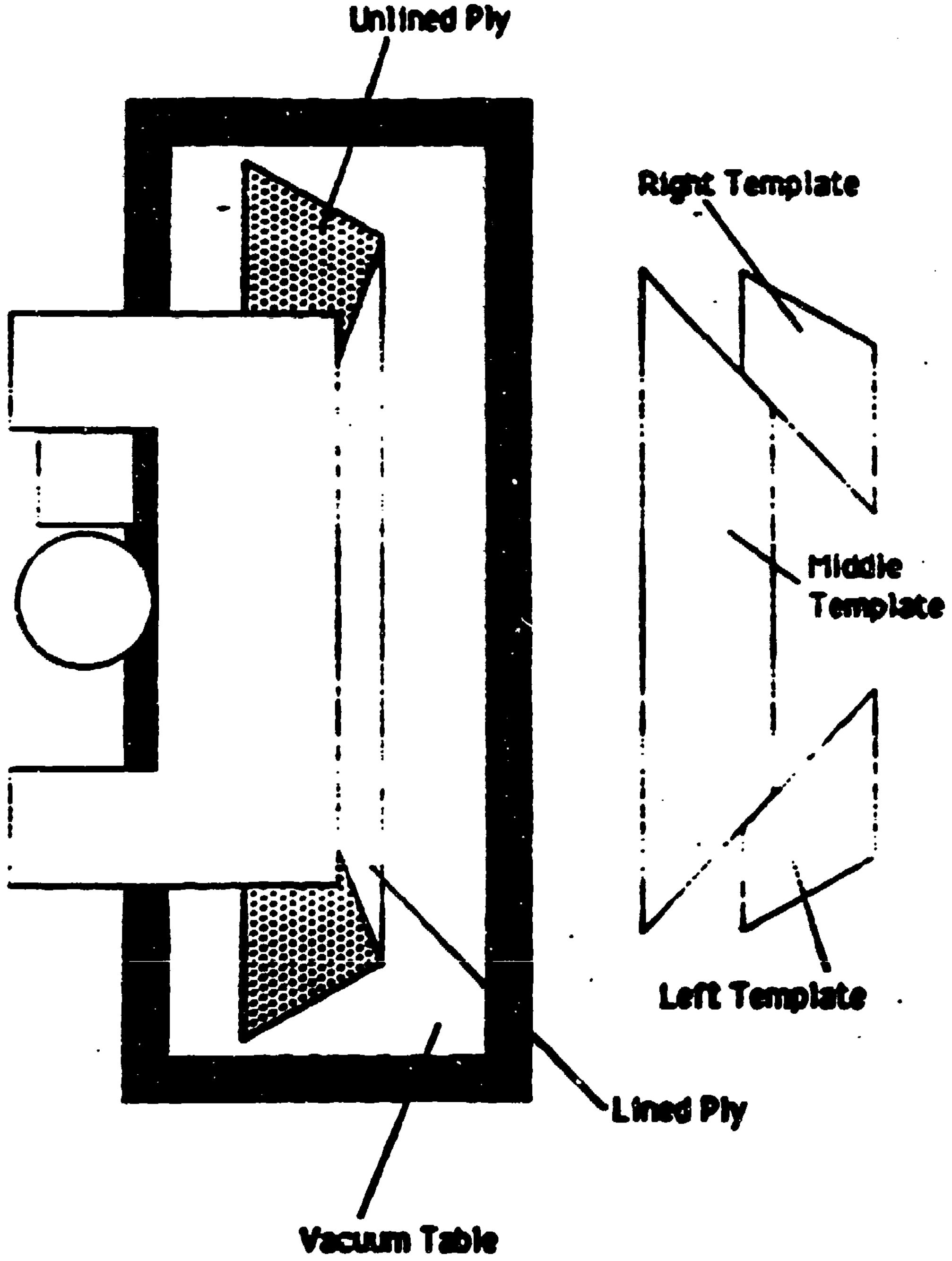

Figure 27. Top View of End-Effector Adjusting Workpiece Position on Vacuum Table

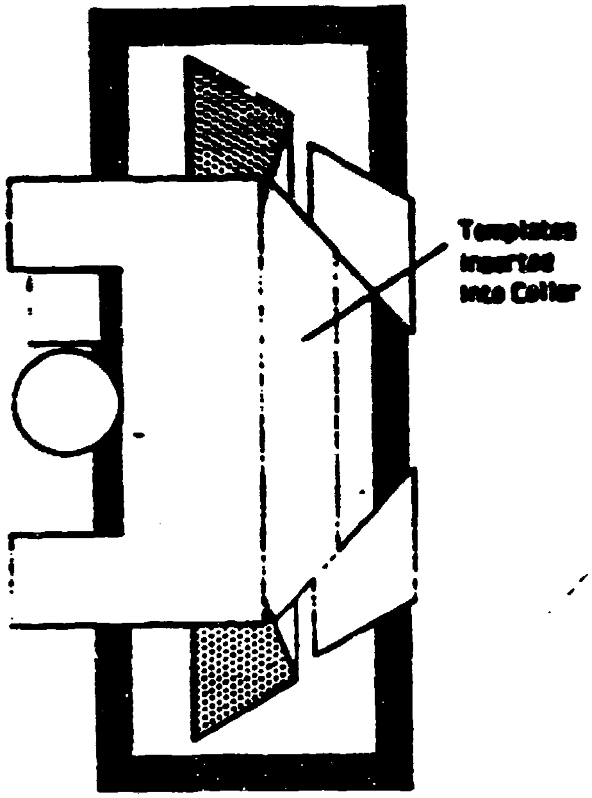

Figure 28. Top View of Template Insertion into Collar Pocket

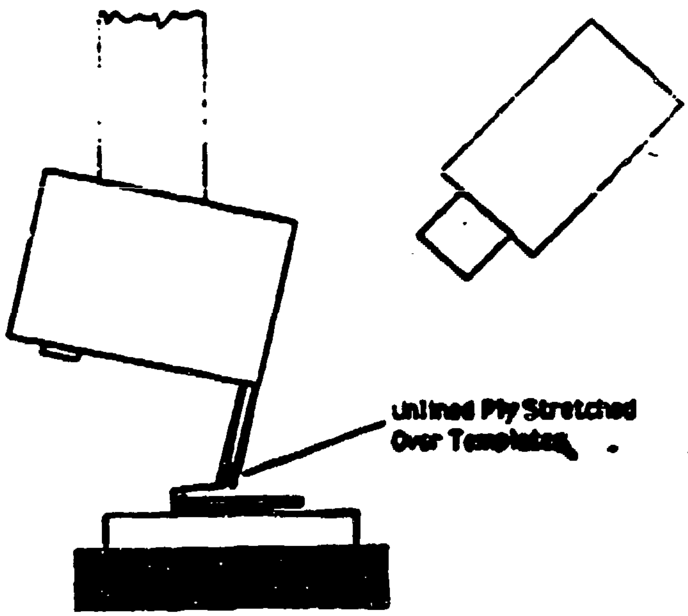

Figure 29. Side View of End-Effector Aligning Collar Seam

PROGRAM STATUS
February 1990

- Robot Installation - Adept (3/1/90)
- Vision System (Operation with study)
- Robot End-Effector (Designed with component selection and manufacturing in progress)
- Turning Device (Manual bench model operational; automated workstation in design)
- Pressing Device (Manual bench concept developed and in progress)
- Systems Integration Software - PC Based (Integration with "C", Prolog and Timeslicer)
- UMI/RTX Robot (Purchase after 7/1/90)

FEBRUARY 15, 1990

CLEMSON UNIVERSITY

MEASURING THE EFFECT OF ERGONOMIC CHAIRS

Chair Ergonomics Study
January 1990 Report
Jack Peck

The study of the productivity benefits derived from the use of ergonomically designed chairs used in the apparel industry began in January 1990. Prior to funding, agreements were reached with Kendall Corporation and Jantzen Corporation, both in Seneca, SC, as well as with Foxfire Technologies Corporation, Adjusto, and the Georgia Tech Research Institute (GTRI) to participate in the study. Kendall and Jantzen have both installed the Foxfire Technologies Corporation Real-time Shop Floor Control System and have large quantities of objective data concerning the performance of shop floor personnel prior to the start of the study. Both Kendall and Jantzen have agreed to make their data and personnel available as part of the study. Adjusto, the manufacturer of the chair to be used in the study, has agreed to supply a small number of chairs to Kendall and Jantzen as part of the study. The GTRI has an ongoing ergonomics study, as part of their DLA funded contract, and have agreed to assist in collecting subjective data relating to use of the chairs through visual and interview techniques.

The primary goal of the study is to collect objective data before the installation of the ergonomically designed chairs and then to collect objective data after the installation to see what, if any, effect the chairs might have on productivity. The Foxfire Real-time Shop Floor Control System provides an accurate time measure of activities such as clock-ins, clock-outs, production start, production stop, moves to off-standard categories, etc. This data will be analyzed to determine absolute changes as well as trends across the day which relate to fatigue or other factors.

A secondary goal of the study is to collect subjective data before the installation of the ergonomically designed chairs to determine what factors the employees consider important in the construction of their current chairs and workstations. Similar information will be collected after the chairs have been installed. Interviews and video tapes will be used to collect this subjective data. Both the subjective and objective data will be correlated to see if similar conclusions result.

A major effort will be made to minimize the Hawthorne Effect, which sometimes yields studies of this nature unreliable. The fact that people are aware that they are being studied will sometimes influence their performance. In the case of the objective study, using data collected from the real-time system before the study began, the Hawthorne Effect will not exist, because the operators will have no knowledge that the study would be conducted. The data collected after the chairs are installed will have minimal effect on the objective data because the operators are not being fully informed that the real-time system data is being collected for this purpose. They will sign a release which simply states that they agree to participate in a study relating to ergonomically designed chairs in which data will be collected an analyzed to determine the benefits of the chairs.

The study using more subjective data may not enjoy the same independence from the Hawthorne Effect. Employees will be aware of the study as soon as they sit through an interview and are being video taped. An interesting byproduct of this research may be to get a rough estimate of the magnitude of the Hawthorne Effect by comparing the results of the objective and subjective studies.

Progress

1. Several students were interviewed for assistance on the project and Mr. Bapiraju Buddhavarapu, a first year graduate student seeking a masters degree in computer science at Clemson University, was selected.

2. An initial meeting with Dr. Dan Ortiz, from GTRI, was held with the Clemson group and representatives of Kendall and Jantzen. Visits to the Kendall and Jantzen plants were made to observe the layout and types of operations being performed. Several concerns of these industrial participants were discussed:

    a. Production should not be significantly interrupted during the study.

    b. Conclusions and other data are to be provided to management rather than to employees. Benefits which may be measured, although possibly positive, may be economically or otherwise infeasible for the company to implement.

    c. Any results of the study can be published; however, the names of the employees and companies involved should remain anonymous.

3. Kendall and Jantzen will each select 5 employees to participate in the study in a manner which will create a sample of people representative of their work force. Factors to be considered include:

    a. both young and older employees,

    b. a variety of operations,

    c. operators well trained in operations with consistent performance before the study started but with room from improvement (i.e. not superstars)

    d. a variety of efficiencies on the operations.

4. Data was extracted from Kendall's backup tapes for the past several weeks and transcribed to diskette. Jantzen's data already exists on diskette and will simply be copied later.

5. Chairs were ordered from Adjusto. While awaiting delivery of the Adjusto chairs, chairs were temporarily borrowed from the Clemson Apparel Research project. GTRI has agreed to provide 3 chairs for the study as well.

6. A video tape, prepared by students in the Industrial Engineering Department at Clemson University and showing methods of adjusting the chair, was provided to both Kendall and Jantzen.

7. Graphs, illustrating productivity changes of employees, to be produced at the conclusion of the study were designed.

8. Studies of the format of Foxfire files were initiated.

9. Programs to extract relevant data from the Foxfire files were designed.

The project is about on schedule with installation of the chairs in the target companies planned for the week of February 19.